Practical Talks on Electricity

BY WILLIAM BAXTER, JR.

PART II.

Care and Management of Dynamos
and Motors.

THE ENGINEER PUBLISHING CO.
355 Dearborn St., Chicago.
1905.

Table of Contents.

For detecting the presence of a current in a conductor, the simplest kind of a galvanometer will answer; such instruments, which are commonly called current detectors, are cheaply made and some of them can be bought for 50 or 75 cents. For making measurements of resistance, it is necessary to have a more accurately constructed instrument. The simplest way in which a galvanometer can be arranged to measure resistance is shown in Fig. 144, but this method is seldom used, except for very high resistances, as it is not accurate.

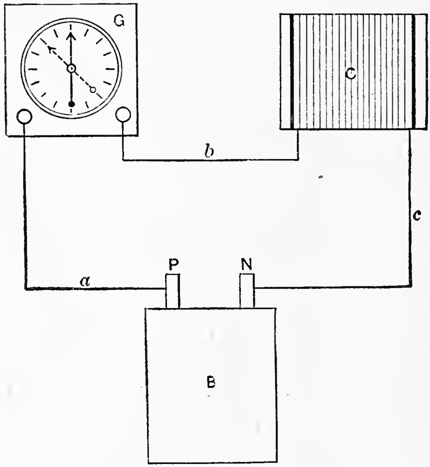

FIG. 144.

In Fig. 144, *G* represents a galvanometer, *B* an electric battery which furnishes the current for making the measurement, and *C*, a spool of wire the resistance of which we wish to ascertain. If the battery *B* is disconnected so that there is no current flowing in the circuit, the needle of the galvanometer will not be deflected, but will point toward the north, which in the figure is in the vertical direction. As soon as the battery is connected, a current will flow and the galvanometer will be deflected.

Suppose it is deflected to the position indicated in the dotted lines; then if we remove spool *C* and substitute for it resistance coils of different sizes, until we get a sufficient number in the circuit to cause the galvanometer needle to be deflected to the same position as with the spool, we know that the resistance in the two cases is the same. If, now, we add up all the resistances we have substituted for *C* and find that they make, say, 10 ohms, we know that the resistance of *C* is 10 ohms.

This method, although simple, is not accurate, for several reasons: First, unless the galvanometer needle is of considerable length, we cannot determine accurately the exact point to which it swings, either with the spool *C* or the measuring resistance we substitute for it. In the second place, unless the current is very weak, the needle will swing through a wide angle and, the farther it swings, the smaller the additional distance it will be advanced by a given increase in current. Thus, if the current is so weak as to cause the needle to swing through an angle of 3 or 4 degrees, doubling the current strength will increase the angle of swing to about double the amount; but if the current is so strong as to cause the needle to deflect 85 degrees, then if the current is doubled, the deflection may not be increased to more than 86 degrees. Thus, it will be seen that, if the current is sufficient to deflect the needle through a considerable angle, the difference in the deflection produced by a small variation in the strength of the current will be so small as to be exceedingly difficult to detect. The third and last of the most serious objections to this method is that, in order to be able to obtain accurate results—supposing that we can determine correctly the deflection of the needle—it is necessary for the voltage of the battery to remain absolutely constant, and it is almost a practical impossibility to make such a battery.

For measuring resistance the method illustrated in Fig. 145 is the one commonly used. It is accurate, and easily understood. In this method, the galvanometer and the resistance coils with which the measurements are made are connected with one another and with a battery that furnishes the current, and the whole outfit is called a Wheatstone bridge testing set, or simply a bridge, or a testing set.

To illustrate the principle of the Wheatstone bridge, sup-

pose the lines in Fig. 145 represent water pipes, and let the point *A* be higher than *C*, so that the current of water will flow from *A* to *C* by the force of gravity. Let *G* be a water meter placed in a pipe running between points *B* and *D*. Now it is evident that if *B* and *D* are on the same level, no water will pass through *G*, and consequently the indicator hand will not move; but if *D* is higher than *B*, there will be a current of water through *G* from *D* to *B*, and, if *B* is higher than *D*, the current will

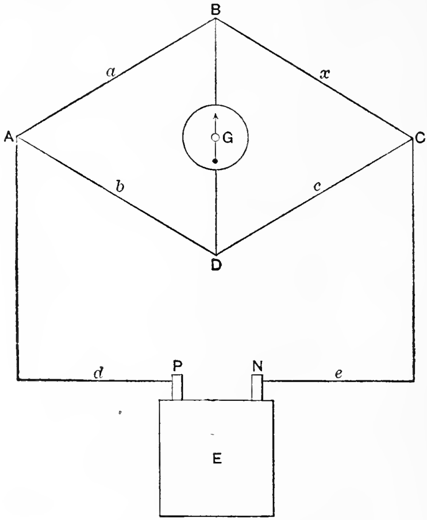

FIG. 145.

flow in the opposite direction. Thus it will be seen that we can determine whether *B* and *D* are on the same level by noticing whether the meter *G* indicates a current or not. If the two pipes *A B C* and *A D C* have a uniform inclination, the distance from *A* to *B* will be the same as that from *A* to *D*; but if the upper pipe has a steep decline near *A* and then runs comparatively level, the distance *A B* will be shorter than *A D*.

This principle, as above illustrated in connection with water pipes, is that of the Wheatstone bridge, but instead of making

use of differences in level, we make use of differences in electrical pressure, or potential, as it is called. To force an electric current from *A* to *C* requires an amount of pressure that is proportional to the resistance and the strength of the current. To force the current from *A* to *B* requires less pressure; hence, we may say that the fall of potential between *A* and *C* is greater than between *A* and *B*. Suppose the resistance between *A* and *D* is 10 ohms, and between *D* and *C* also 10 ohms; then, if the voltage acting to force the current from *A* to *C* is 20 volts, the current will be 1 ampere, and as the resistance from *A* to *D* is 10 ohms, the fall of potential between *A* and *D* will be 10 volts.

Now let the resistance from *A* to *B* be 20 ohms and from *B* to *C* also 20 ohms; then the total resistance from *A* to *C* through *a* and *x* will be 40 ohms, and as the pressure acting between these points is 20 volts, the current will be ½ ampere. Now, $\frac{1}{2} \times 20$,—*i. e.*, current in *a* times the resistance of *a*—is equal to 10 volts. Hence the fall of potential from *A* to *B* is 10 volts, and this is the fall of potential from *A* to *D*, so the electrical pressure at *B* and *D* is the same, and as a consequence no current will flow through the wire and the galvanometer *G*.

From the foregoing it will be seen that, if we connect between the points *B* and *C* the conductor whose resistance we desire to measure, and then insert between *A* and *B* resistance measuring coils until no current flows through the galvanometer *G*, then the resistance at *x* and the resistance of the measuring coils at *a* will be equal. With this method, very accurate results can be obtained, as the smallest possible current passing through a sensitive galvanometer at *G* will cause the needle to deflect through a noticeable angle. Hence, we can determine with extreme accuracy the condition when the resistance *x* and the measuring coils *a* just balance each other.

In order that the instrument may have a wide range of measurement, the resistances of the branches *b* and *c* are made so as to be varied. To illustrate the effect of such variations, suppose that *b* is made 100 ohms, and *c* is 1 ohm. Then the total resistance from *A* to *C* through the lower sides of the figure will be 101 ohms; and if we have an electromotive force of 101 volts, the strength will be 1 ampere, so that the fall of potential between *A* and *D* will be 100 volts. Now suppose we place a

conductor in the side, *x*—that is, connected between *B* and *C*—and suppose that to obtain a balance so that no current flows through the galvanometer, we have to insert at *a* 10 ohms. Then we shall know that the resistance of the conductor at *x* is 0.1 ohm; or by adding this 0.1 to the 10 ohms at *a*, we shall have a total resistance from *A* to *C*, through *a* and *x*, of 10.1 ohms, and as the voltage between these points is 101, the current strength will be 10 amperes, and this multiplied by the resistance of 10 ohms, at *a*, gives just 100 volts, which is the same fall of potential as we found between *A* and *D*. Thus it will be seen that if the resistance of *b* is made 100 times as great as that of *c*, the resistance *a* will be 100 times as great as the resistance *x*, which we desire to measure. If we reverse the order of things, and make *c* 100 times as great as *b*, then the resistance at *x* will be 100 times as great as the measuring resistance at *a*.

Testing sets for general use are arranged so that the resistances of *b* and *c* can be made equal, or *b* can be made 100 times as great as *c*, or *c* 100 times as great as *b*. By means of these changes, the capacity of the instrument is made 10,000 times as great as that of the measuring coils, and the smallest resistance that can be measured is the one-hundredth part of the lowest of the measuring resistances. The lowest of the measuring resistances is generally 0.1 ohm; so that the smallest resistance that can be measured at *x* with the instrument, is 0.001 ohm. The sum of all the resistance coils of the instrument is generally 11,000 ohms; so that the largest resistance that can be measured is one million, one hundred thousand ohms.

Special bridges are made that have a greater range, and some are graduated for much smaller resistances, but with the same total range.

Fig. 146 shows a Wheatstone bridge testing outfit. The battery is placed in the right-hand side of the box, the galvanometer is at the back and the measuring resistances are connected with the rows of discs in front of the galvanometer. The conductor to be measured is connected with the binding posts on the left-hand side of the box.

In making a test, after the conductor is connected with the binding posts, the switch key at the front is depressed, closing the circuit, and instantly the galvanometer needle is seen to

swing violently to one side. We now set the plugs in holes so as to connect some of the measuring resistances in the circuit, and again depress the switch key. If the needle now swings to the opposite side, we know that we have inserted too much resistance and proceed to cut some of it out, by changing the

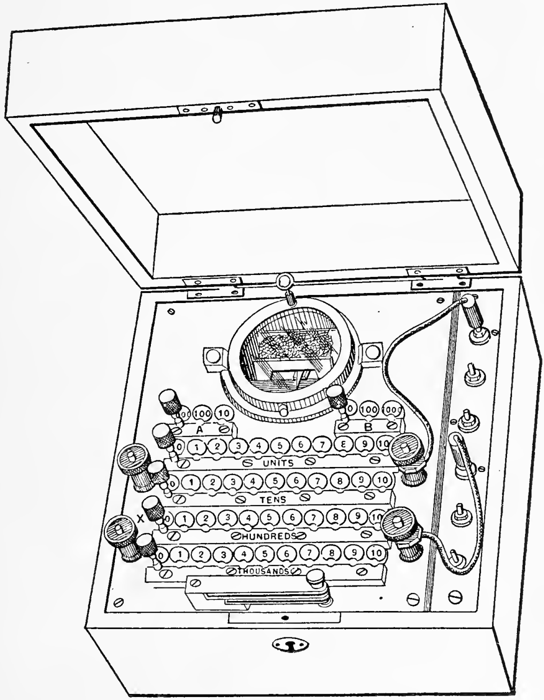

FIG. 146.

position of the plugs. When we get very near to a balance, the needle will swing more slowly out of the central position, and when a perfect balance is obtained, it will not move at all when we depress the key.

Having reached this point, we add up all the resistances

inserted in the circuit and then, by noting whether the resistances *b* and *c* are equal or not, we know whether this sum is the true resistance of the object we are measuring, or whether it is to be divided or multiplied by ten or one hundred. It will be noticed that next to the galvanometer, there are three plug holes on each side, one marked *A* and the other *B*. These are the *b* and *c* resistances of Fig. 145, and the figures on the disks state whether, with the plugs in certain holes, the reading is to be taken even, or whether it is to be multiplied or divided.

CHAPTER XXVIII.

Care of Electrical Machines.

AFTER an electrical generator or motor has been in use for several years it is liable, like other machines, sometimes to act badly. It will be examined, and sometimes a correct conclusion is reached, but very often not.

If a machine is old, it is more than likely that the shaft will be found out of center, and if this fact is discovered at a time when things are not working as they should, it is taken for granted that this is the cause of the trouble. For the present it will be sufficient to investigate just what effect displacement of

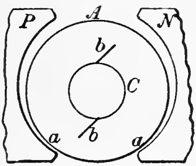

FIG. 147.

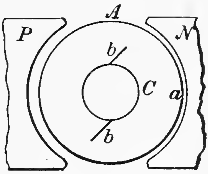

FIG. 148.

the shaft can have; then, if the trouble with a machine so afflicted is not in the category of shaft disorders, we shall know that we must seek further for the cause of the complaint.

Fig. 147 illustrates an armature of a two-pole machine which is out of center in one direction, and Fig. 148 shows another two-pole armature out of center in a direction at right angles to that shown in the first figure. The condition shown in Fig. 147 could be produced by a heavy armature running in rather light bearings for several years, and the side displacement of Fig. 148 could be produced by the tension of an extra tight belt. The mechanical effect of both these conditions would be to increase the pressure on the bearings, as the part *a* of the armature would be drawn toward the poles of the field with greater force than the opposite side. The downward pull due to the attraction of the magnetism, would be greater in Fig. 147 than the

side pull in Fig. 148, supposing both armatures and fields to be the same in both cases, and the displacement of the shafts equal. This difference is due to the fact that in Fig. 147 the magnetism of both poles is concentrated at the lower corners on account of the shorter air gap. Hence, both poles pull much harder on the lower side.

In Fig. 148, the pull of the *N* pole is greater than that of the other, simply because in the latter the magnetism is more dispersed, but the difference in the density on the two sides will not be very great. If the bearings of a machine, with the armature displaced as indicated, have shown any signs of cutting, or if they run unusually warm, their condition will be improved by putting in new bearings that will bring the shaft central.

If the armature is of the drum type, the displacement of the shaft will have no effect upon it, electrically. This is owing to the fact that all the armature coils are wound from one side of the core to the other, and, therefore, at all times every coil has one side under the influence of one pole and the other side under the influence of the opposite pole, and if one side is acted upon strongly by one pole, it will be acted upon feebly by the other.

If the armature is of the ring type, then the displacement of the shaft will affect it electrically, for in a ring armature the coils on one side are acted upon by the pole on that side only and as the magnetic field from one pole will be stronger than that from the other (that is, considering the action upon equal halves of the armature), the voltage developed in the coils on one side of the armature will be greater than that developed on the other side.

In Fig. 147, if the brushes *b b* could be placed on the vertical diameter, as shown, the electrical action would not be interfered with, for on each side of the vertical line the magnetic action would be the same. But the reaction of the magnetism developed by the armature current twists the magnetism around, so that the brushes have to be rotated around some distance from the vertical line; therefore, even in the case of Fig. 147 the electrical balance will be disturbed, if the armature is of the ring type.

The effect of this disturbance of the electrical balance will

be that the brushes will spark badly, because the voltage of the current generated on one side of the armature will be greater than that of the current on the other side. Hence, when these two currents meet at the brushes, the strong one will tend to drive the weak one backward. If, while the armature is out of center, we wish to adjust the brushes so as to get rid of the excessive sparking, all we have to do is to set them to the right of the center line in Fig. 148, so that the wire on the left side will cover a greater portion of the circumference than that on the right; or, what is the same thing, so that there will be more commutator segments between the brushes on the left side than on the right. In this way the voltages of the two armature currents can be equalized, and the sparking can be cured, or very nearly so.

In a multipolar machine, the displacement of the armature will have the same effect mechanically as in the two-pole type; that is, it will increase the pressure on the bearings and probably cause them to cut, or at least to run warmer than they should.

The effect produced upon the electrical action will depend upon the way in which the armature is wound, or, more properly speaking, upon the way in which the armature coils are connected with each other and with the commutator segments. Multipolar armatures are connected in two different ways, one of which is called the wave or series winding, and the other the lap, or parallel winding. (See Chapters XI and XII, Part I.)

In the first named type of winding, the ends of all the coils on the armature are connected with each other and with the commutator segments in such a manner that there are only two paths through the wire for the current; therefore, these two armature currents pass under all the poles and the voltage of each current is due to the combined effect of all the poles. From this very fact it can be clearly seen that it makes no difference what the distance between the several poles and armature may be, for if some are nearer than the others, the only effect will be that these poles will not develop their share of the total voltage, but whatever their action may be, it will be the same on the coils in both circuits.

When a multipolar armature is connected so as to form a

parallel or lap winding, the connections between the coil ends, and between these ends and the commutator segments, are such that as many paths are provided for the current as there are poles, and each one of these paths is located under one pole so that the voltage developed in it is proportional to the action of this pole. The diagram Fig. 149 illustrates a six-pole armature with the ends of the field poles, and the arrows *a a, b b, c c,* indicate the six separate divisions of the coils in which the branch currents are developed.

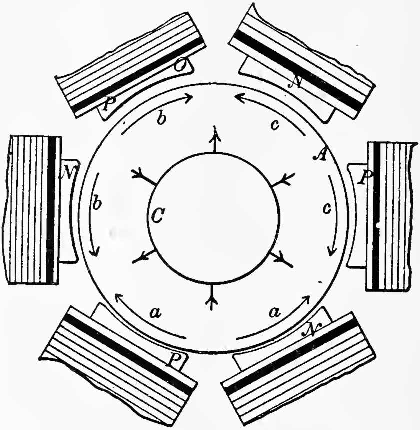

FIG. 149.

Now it can be clearly seen that as the armature is nearer to the lowest poles than to any of the others, the action of these will be the strongest. Hence, the currents *a a* will be stronger than the others and will have a higher voltage. These two currents will be taken off the commutator by the brushes at the lower corners. These same brushes also take off the currents developed by the action of the side poles, and which are indicated by the side arrows *b c*. These last two currents will be weaker and of lower voltage than the *a a* currents; hence, the latter will try to crowd them back and thus sparks will be produced at these brushes.

The two upper currents are weaker than the side ones, and their voltage is also lower, so that the current returning to the commutator through the brushes at the upper corners will not divide equally, but the larger portion will be drawn into the coils on the side; and as the upper coils will have to fight to hold their own, so to speak, there will be a disturbance of the balance that is required for smooth running. The result will be heavy sparking at these brushes.

If these four brushes were shifted downward, the lower ones being moved more than the upper ones, points could be found where the sparking would disappear. This readjustment of the brushes would be the same thing for a multipolar machine as the shifting to one side explained in connection with the action of a two-pole ring-wound armature. Multipolar machines, however, are seldom made so that the brushes can be moved individually, so that we cannot count on correcting the trouble temporarily in this way. In the great majority of cases, if the brushes of a multipolar machine spark on account of the armature being out of center, the only cure is to reset the bearings, if they are adjustable, and, if they are not, to put in new ones.

In two-pole machines we have seen that, if the armature is of the drum type, the action of the brushes will not be affected by the displacement of the shaft, and this will also be the case in a multipolar machine, if the armature is wave or series wound. From this it will be inferred that there is a similarity between the two-pole drum winding and the multipolar wave winding, and such is really the case. The multipolar lap winding is the counterpart of the two-pole ring winding, and, in fact, a ring-wound armature will work perfectly in a machine with any number of poles, provided we place upon the commutator as many brushes as there are poles.

If we made a ring armature and provided a number of different fields into which it would fit properly, one being two-pole, one four-pole, one six-pole, one eight-pole, and the others of greater numbers of poles; then, if each machine had as many brushes as poles, and these were set in the proper position, the armature would run as well in one as in another, without requiring any changes in the connections between the armature

coils and the commutator. In fact, all we should have to do would be to remove it from one machine and place it in another and it would be ready to run.

For multipolar machines the regular ring winding is not often used, because the coils have to be wound in place, and are, therefore, not so mechanical in appearance, and are more expensive to make. The formed coils almost universally used for multipolar armatures have both sides on the outer surface of the core, and on that account, when they are connected into a lap winding, they will not operate perfectly with a number of poles different from that for which they are connected, but they will run, after a fashion, with any number of poles. That is, if we have two generators with four and six poles respectively, both using armatures of the same diameter, and both lap wound, if one armature gives out, we can use the armature of the other machine as a makeshift. An armature with a wave winding cannot be used except with a field of the number of poles for which it is wound.

As it may sometimes be advantageous to change an armature from one machine to another while repairs are being made, provided the dimensions of the machines are the same, it is desirable to know how to determine whether the winding is wave or lap connected. This is explained in Chapter XIII, Part I.

CHAPTER XXIX.

Management of Generators.

ELECTRICAL generators are made of two types so as to develop two different types of currents. One of these maintains a constant voltage and the other a constant amperage. With the first-named type, the amperes increase and decrease in accordance with the demands of the circuit, and in the second type the volts change in the same way. It must not be supposed that these two types of current represent different kinds of electricity. The difference between the two types is precisely the same as the difference between two streams of water, one of which keeps the pressure constant, and increases or decreases in volume, while the other keeps the volume constant and varies the pressure.

Electric generators that maintain the amperes constant are called constant current generators, and those that keep the volts constant are called constant potential generators. Machines of the first-named type are used for arc lighting, while those of the second type are used for incandescent lighting, for operating stationary motors and electric elevators, and also for electric railways. In the early days of the electrical industry, electric generators were called dynamos and the name is still used by the majority of people to designate arc light machines. The number of arc light generators used outside of lighting stations is very small in comparison with the number of constant potential generators, probably not more than 1 per cent of the latter. On this account, what we have to say in this chapter will refer to the constant potential machines.

Constant potential machines are of three different types, so far as the current is concerned. The simplest type is the shunt machine, which does not maintain the voltage absolutely constant, but suffers a slight reduction as the strength of the current increases. A well proportioned shunt generator will not vary its voltage more than 2 or 3 per cent from full load down to the lightest load, provided the speed at which it runs does not change. If the capacity of the generator is, say, 500 lamps, and it develops

110 volts with the full number of lights in operation, it will develop not more than 112 to 113 volts when only one lamp is burning.

This would be the result if the speed did not change; but as a matter of fact, the speed will change, because the best governed engines will run slightly faster with a light load than with a heavy one. A well governed engine will increase its velocity between 3 and 5 per cent between no load and full load, and this change in speed will cause the voltage of the generator to vary more than stated above. Hence, in actual practice, a well proportioned shunt generator driven by a well designed engine will vary its voltage from 6 to 9 per cent between full and light load, so that if, with all the lights burning. the voltage is 110, with only one lamp in service, it will be anywhere from 116 to 119 volts.

In practice, however, the number of lights does not vary within such wide limits, the fluctuation being, as a rule, probably not more than one-half as much, so that the actual variation in voltage is seldom more than 2 or 3 volts. This, however, is the variation of the pressure at the terminals of the machine; but if the lamps are located at a considerable distance from it, the fluctuation to which they will be subjected will be greater, because the portion of the voltage absorbed by the resistance of the line wires will increase as the current increases, and decrease with current decrease.

The only way in which these changes in voltage can be compensated for with a shunt generator is by varying the amount of rheostat resistance introduced into the field coil circuit. Many devices have been made that change this resistance automatically and some of them are simple and work well. If the number of lights in use is continually varying, the only way in which the voltage can be kept constant is by the use of one of these automatic regulators; but if the number of lights remains constant for a considerable length of time, and the increase or decrease takes place at more or less regular intervals, then the field rheostat can be changed by hand and the results obtained will be very satisfactory.

The principle upon which a field rheostat acts can be explained by the aid of Fig. 150 and then the way in which it

should be manipulated to vary the voltage in any desired degree will be readily understood. In this diagram, the circle *A* represents the generator armature, and *M* represents the field coils, while *R* is the rheostat. The bar *C* together with the contacts above it, which are connected with the several loops of the rheostat, and the lever *D*, constitute the rheostat switch, by means of which the resistance is cut into or out of the field circuit. The lines *P* and *N* represent the line wires through which the

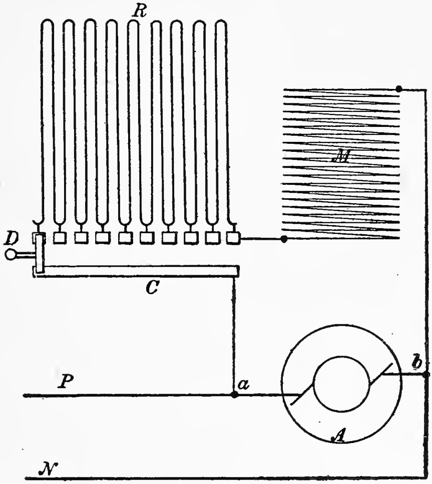

FIG. 150.

current passes to the lamps. The points *a* and *b* represent the binding posts of the generator. From post *a*, a connection runs to bar *C*, and with the lever *D* in the position shown, the current that traverses the field coils *M* will also have to pass through all the resistance of *R*.

Under these conditions the field current will be weak, and as a result the field magnetism will also be weak. Now the voltage developed in the armature at a given speed of rotation, will depend upon the strength of the field magnetism, being low when the latter is weak, and high when the latter is strong.

From this it will be seen that when the field current traverses all the resistance of *R*, the voltage will be the lowest obtainable at the speed at which the generator is run, and that with all the resistance of *R* cut out of the field circuit, the voltage will be the highest. The movement of *D* toward the right cuts out the sections of *R* consecutively, all of the resistance being removed from the field circuit when *D* rests on the last contact on the right-hand side. Any voltage between the highest and lowest can be obtained by placing *D* at points between the extreme right and left positions.

Suppose a generator of five hundred lights capacity is used in a building in which about one-fifth of the lamps are in service during the day, and say four to five hundred at night from 6 to 10 o'clock, after which hour the number drops off to about twenty, at which it remains until the next morning. In such a building, there would be two periods during the whole day when the rheostat would have to be manipulated to keep the lamps burning at the normal brilliancy. These periods would be when the night load begins, and when it drops off. From midnight, to about 6 o'clock the next evening, the number of lights would range between about twenty and, say, sixty; so that, if the rheostat is set at midnight, when the small number of lights are in use, to about ½ volt above the normal pressure, it will be right for the day load, as increasing the lamps to sixty will not reduce the voltage too much.

At the hour when the night load is about to commence, the attendant should keep his eye on the voltmeter and as fast as the pressure drops, the rheostat switch should be turned, so as to cut out the resistance and thus raise the voltage again to the standard point. In the course of half an hour or so, all the lights will be turned on, and the rheostat will not have to be looked after again until the time comes when the lights begin to be turned off. During this period, the voltage will rise as the lamps go out, and to keep it down to the standard, lever *D* will have to be moved toward the left, so as to cut more resistance into the circuit.

Field rheostats as actually used are not of the form illustrated in Fig. 150, but they are connected in the field circuit in the way shown, and their action is as explained. Most rheostats

are made in the shape of a box, and vary from a foot square to two or three times this size. The switch part is located on the front of the box and is arranged in the manner shown in Fig. 151. The stud *C* takes the place of rod *C* in Fig. 150, and the switch *D* is the counterpart of *D* in the first diagram. The circle of contacts *E* are connected with the sections of the resistance in the same way as the contacts in the straight row above *D* in Fig. 150. At the ends of the circle of contacts, stops *a* and *b* are placed so as to prevent the switch from being moved entirely off the contact, and thus opening the field circuit.

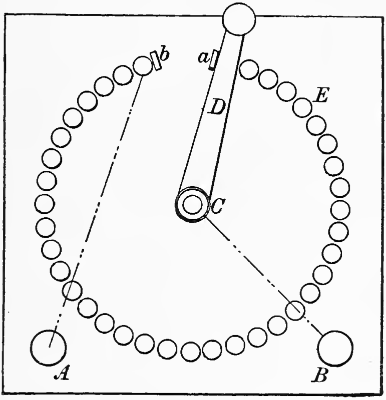

FIG. 151.

If the field circuit is opened from any cause, the machine will stop generating; therefore, it is necessary not only to provide these stops, but also to make all parts of the switch so perfect, mechanically, as to render defective contacts at any point next to impossible. It may also be well to add that all the connections in the field circuit, whether in the rheostat or elsewhere, must be carefully watched and not be allowed to get loose. A slightly imperfect joint in the field circuit may not stop the generation of current entirely, but it will lower the voltage, and if it is in such a condition that the contact becomes good

and bad by turns, the voltage will rise and fall, thus causing the lights to vary in brightness. A loose wire in a binding post, if so supported that it can swing or vibrate, may cause the voltage to dance up and down in such a manner as to lead to the conclusion that something serious has happened to the generator.

If the current developed by a generator is supplied to lamps that are near by, say within 100 feet, a shunt machine will meet the requirements perfectly; but if some lamps are within this distance while others are 500 or 600 feet away, a compound generator will give better satisfaction.

As we have seen, the shunt machine can be made to keep the voltage about constant at its terminals by the aid of the field rheostat, but the voltage at the lamps under these conditions will not be constant, owing to the fact that a part of it is absorbed in overcoming the resistance of the line wires. Now suppose that at a distance of, say, 500 feet from the generator there are two hundred lamps to be operated and that of these there will be only twenty or thirty in use during a portion of the time, while during the remainder of the day all the lamps are in use. Under these conditions, the voltage lost in driving the current through the line when all the lamps are used will be greater than when the number is small; hence, if the pressure is right when all the lights are in service, it will be too great when only a few are burning.

If a compound wound generator is used, the voltage can be kept the same when the number of lights burning is large or small, because such a machine can be adjusted so that as the current generated increases, the voltage increases, and if this increase is just equal to the greater loss in the line, then at the distant lamps the pressure will remain the same at all times. At the nearby lamps, however, the voltage will rise as the number of lights in service increases. In order to obtain the best results in such cases, the machine is so proportioned that the lamps about midway between the farthest and the nearest will have the same voltage at all times, and then the nearby ones will have slightly too great a voltage when the load is heavy, while the distant ones will not have quite enough, but the variation in pressure at any of the lamps will not be sufficient to make a noticeable difference in the brightness of the light.

When a machine is adjusted so that the voltage at the terminals increases as the current increases, it is said to be overcompounded, a compound-wound machine being one which maintains the voltage constant at the terminals. To make a generator compound or overcompound, the field is provided with two sets of coils, one being made of many turns of fine wire and the other of a few turns of large wire. The first set is the shunt coils, and the second is the series or compounding coils. The current through the shunt coils is derived from the terminals in the same way as in a simple shunt machine, but the current for the series coils is the entire current of the armature; that is, the armature current does not pass out directly to the external circuit, but first passes through the series field coils.

Upon the strength of current flowing through them depends the magnetizing action of these series coils. Therefore, when the armature is generating a large current the series coils act more energetically upon the field. Thus it will be seen that the office of the series or compounding coils is to assist the shunt coils and we can further see that, if a certain number of turns of wire in these coils will enable them to assist the shunt coils sufficiently to keep the voltage just constant, then a greater number of turns will so increase the assistance they give as to cause the voltage to rise as the current increases. The difference, therefore, between a compound and an overcompound generator is simply that the latter has more turns of wire in the series coils.

CHAPTER XXX.

How to Find Out Whether Two Generators Can Be Run in Parallel.

IT IS OFTEN desirable to determine whether two generators can be connected in parallel; that is, whether they can be connected so as to feed into the same circuit. One who does not understand the subject would be likely to take it for granted that, if they are of the same size, or nearly so, they will work all right, but that, if one is much larger than the other, they will not. This conclusion, however, is far from being correct; in fact, the size has little, if anything, to do with the matter.

For two generators to run together in the same circuit, all that is necessary is that they both develop the same voltage. The action of two electric generators working on the same circuit is the same as that of two pumps delivering water into the same pressure tank. If one pump has a cylinder 2 inches in diameter, and the other one is 2 feet, they will work in perfect harmony and each one will do its share of the pumping, if both develop the same pressure. If, however, the small pump, when running at its normal speed, can develop a pressure of 100 pounds, and the large one can only work up to 90 pounds, then the small one will run above its velocity until its pressure drops to the same point as that of the large one, and it will do a great deal more than its proportion of the work.

Between two pumps and two generators the comparison is not perfect, because the two pumps will work at practically a constant output, while the two generators will have to vary the work they do, probably two or three to one. If the two pumps were arranged so that their combined work would range from, say, 200 gallons to 1,000 a minute, they would furnish an exact parallel to the two generators. Now, if the amount of water delivered by the pumps was to be varied without changing the speed, then the capacity could be varied by changing the stroke of the pistons. This could be accomplished by having the crank-

pins arranged so that they could be moved in or out from the center.

With such an arrangement, it is evident that it would be possible for the devices by means of which the cranks are moved to be so proportioned that the stroke of both pumps would be changed alike, and on the other hand they could be so proportioned that the strokes would not change alike. If as the amount of water pumped varied, the strokes of the two pumps were changed by corresponding amounts, then, if the pressures of the two were the same for one stroke, they would be the same for all strokes. On the other hand, if the strokes are not changed by corresponding amounts, then the pressure of the two pumps would be the same for a certain length of stroke, but for all other lengths it would not, and as a consequence, there would be only one rate of pumping at which the two machines would operate properly. Above or below this point one pump would do more than its share of the work. If the small one did more for large outputs, the large one would do more for the smaller outputs.

All the foregoing is true with respect to two generators; that is, if they are to work together on a variable load, they must be able to develop the same pressure for corresponding increases or decreases in the strength of the current. This fact we can illustrate more clearly by the aid of Figs. 152 and 153. Suppose we have two generators, which, for the sake of simplicity, we will assume to be of the same capacity. Suppose that one of them develops a voltage of 112 when the current is practically zero. When the current delivered is 20 amperes, suppose the voltage is 111 and at 35 amperes let it be 110, while at the maximum output of 80 amperes it is 105 volts.

If such is the performance of the machine, we can represent it by a curve such as *A* in Fig. 152. In this diagram, the vertical lines measure off the amperes, and the horizontal lines the volts. The vertical line to the left represents zero amperes, and the top horizontal line represents 112 volts. Now, in the foregoing we have assumed that when the current is practically zero, the voltage is 112. Hence the curve *A* must start from the point where the zero ampere line and the 112-volt line intersect, and this is the starting point in the diagram.

We have further assumed that when the current is 20 amperes, the voltage is 111, and by looking at the diagram we shall find that the vertical line 20 and the horizontal line 111 meet the curve at the same point. In the same way the vertical line 35, and the horizontal 110 meet at another point of curve *A*. The curve *A* is called the characteristic curve of the generator, and from examining it we can see at once the relation between the change in strength of current and voltage.

Let us suppose now that we had another generator of the same size as the one which gave the curve *A*, and that curve *B* is the characteristic of this second machine. By comparing

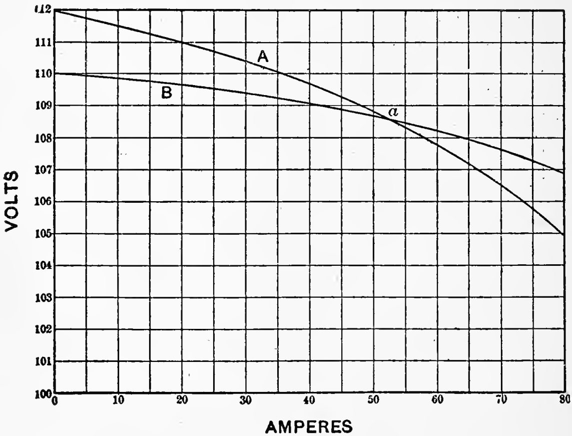

FIG. 152.

these two curves, we find that the rate at which the voltage changes in the two generators is not the same, for that of machine *A* drops 1 volt by the time the current reaches 20 amperes, while machine *B* does not lose 1 volt until the current is a trifle more than 40 amperes. Thus the *B* machine keeps up a more even voltage than the other. The two curves cross each other at the point *a*, and from this we see that, if we could keep the current constant at about 105 amperes, so that each machine would have to develop 52.5 amperes, the two generators would

work together in a satisfactory manner; but if the current increased beyond this amount, machine *B* would do more than *A*, while for a decrease in current *A* would do the more work.

Suppose that the characteristic curves of the two generators were as represented in Fig. 153, then for all strengths of current, *A* would develop a voltage that would be about the same amount higher than that of *B*. From this fact we would at once infer that, if we increase the speed of *B* sufficiently to enable it to give the same voltage at, say, 10 amperes, as machine *A*,

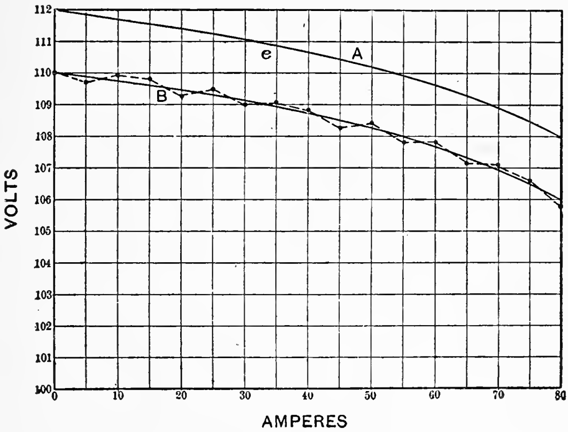

FIG. 153.

it would give the same voltage as the latter with any other strength of current. Hence, these two generators would work together with a varying current and at all times each one would do its proper share of the work.

By the foregoing process we can determine whether two generators of the same capacity will work well together, and by the same means we can determine whether machines of widely different capacities can work together. To accomplish the latter result, all we have to do is to draw the characteristic curves to different scales, so far as the amperes are concerned.

To illustrate this point more clearly, suppose that machine *B* works up to only 40 amperes, then if we draw its characteristic with the same scale for the amperes as we use for machine *A*, the curve would be only one-half the length of curve *A*, and we could not tell from looking at the two whether they would agree or not.

If, however, we were to use a scale twice as great for the amperes of the small machine, then its characteristic curve would be the same length as that of *A*. Thus it will be seen that the curve *B* can be the characteristic of a machine that gives a maximum current of 40 amperes, provided we take the divisions on the horizontal, ampere scale, to indicate 2½ amperes instead of 5. We can further make *B* the characteristic of a 20-ampere machine by making the divisions of the horizontal scale measure 1¼ amperes. Thus it will be seen that to compare the characteristic curves of generators of different capacities, all we have to do is to so proportion the scales for the amperes that both curves will be of the same length.

It will be noticed that in these diagrams, the vertical scale, which measures the volts, runs from 100 up, instead of from zero. We do this so as to represent the volts on a larger scale and thus cause the curves to drop faster. If we used the same scale as for the amperes, 5 volts to a division, the curves would run so nearly parallel with the horizontal lines that we could not determine the volts as accurately as with the larger scale.

It may be said that, although the foregoing explanation of the way in which we determine whether two generators will run together, is simple enough, it is of no value except to those who know how to obtain the characteristic curves of the machines. This is very true, but it is a simple matter to obtain the characteristics, as will be presently shown. Testing of every kind is simply the art of measuring, and if you have the proper instruments, and know how, it requires but little more ability to make a test of an electric generator and obtain its characteristic, than to weigh a pound of cheese or measure a piece of steam pipe. The writer has seen many apprentice boys, 16 to 18 years old, who could obtain these curves as accurately as any one.

The course of procedure is as follows: Obtain an ammeter of sufficient capacity to measure the maximum current of the

machine, and also a voltmeter of proper capacity. Arrange a sufficient number of lamps or resistance coils to carry the full current. The generator should be driven by an engine that runs with as little variation in speed as possible.

Connect the voltmeter with the terminals, and the ammeter in the main line, so as to measure the total current generated at any time. Obtain a speed counter so as to get the speed of the armature when the instruments are read. Rule a sheet of paper in the same manner as Figs. 152 and 153, so as to mark on it the readings as obtained. Having done all this, you first start the generator and obtain the voltage of the machine with the main line open, that is, with zero current. Make a dot on the zero ampere line, on the ruled paper, at a point which indicates the volts shown by the voltmeter. At the same time that the volts are read, take the speed of the armature, and make a note of it.

Now cut in lamps until the current rises to 5 amperes, and again take the voltmeter reading, and the speed. Mark this reading on the 5-ampere line, and then cut in more lamps so as to increase the current to 10 amperes. With this current read the voltmeter and the speed again and mark the result on the 10-ampere line. Proceed in this way until the current has been increased to the maximum amount, and you will find that the result is a number of dots, as shown on both sides of curve *B* in Fig. 153. By connecting these points you will get a zigzag line.

This line will not show the true relation between the volts and the amperes, for, if it did, it would indicate that the action of the machine is very irregular. A curve drawn through these points, so as to strike a general average, will be the actual relation between volts and amperes. The irregularity in the actual measurements is due to the difference in the speed of the armature at the instants when the readings are taken, and also to the fact that as the pointers of the instruments vibrate, to some extent, it is not possible to get the exact results. To make as accurate a test of a machine as possible requires three men, one to read the volts, one for the amperes and one for the speed. In this way, by working at a given signal, all the readings can be taken very nearly at the same instant.

CHAPTER XXXI.

Connecting Generators in Parallel.

WHEN two or more generators are connected with a switchboard so as to feed into the same circuit, it is necessary to start and stop them in a certain way in order to avoid trouble; and, while in operation, several points have to be looked after to secure satisfactory results and also to prevent accidents. What has to be done depends to some extent upon the type of machines—that is, whether they are shunt or compound wound.

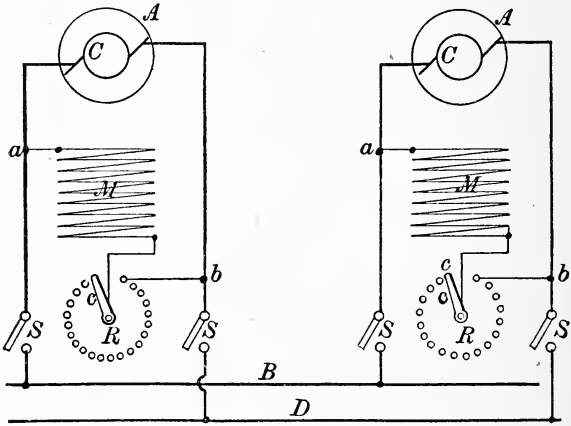

FIG. 154.

Fig. 154 is a diagramatic illustration of two shunt-wound generators connected with the same distributing mains. The lines *B D* represent the bus bars located at the back of the switchboard, and these are in reality nothing but the ends of the distributing mains through which the external circuit is supplied. The two generators are connected with these bus bars by means of the switches *S*, and, as will be noticed, all these switches are

open so that both machines are entirely disconnected from the circuit. This is the way they should be when the generators are not running.

To start up, the machines are set in motion, without turning the *S* switches, and as can be seen, under these conditions the only path for the current generated in the armatures *A A* is through the field coils, each machine having its own field coil as a circuit. When the generators are running at full speed, the rheostat of one of them is adjusted so that the voltmeter indicates the proper voltage. This having been done, the two switches *S S* are closed so as to connect the generator with the buses *B D*, and thus with the external circuit.

We now turn our attention to the second generator, and adjust its rheostat so that the voltage is a trifle higher than that of the first machine, say 1 volt more. Having done this, we close the *S S* switches so as to connect the second machine with the circuit. The next point to observe is the amount of current delivered by each generator, which should be its proportion of the load. Thus, if both machines are of the same size, both should develop equal amounts of current. If one machine is twice as large as the other, then the currents should be in the ratio of two to one. To be able to read the currents of both generators without trouble, there should be provided on the switchboard two ammeters, one for each machine.

If one machine is found to be delivering more than its share of the current, which is likely to be the case, it will show that its voltage is slightly too high, and to adjust it to the proper point all we have to do is to turn the field rheostat *R* so as to cut in a little more resistance. It is probable that when the second generator is cut into the circuit, the adjustment of the voltages will be imperfect, for the reason that the voltage of the machine already in circuit is that which corresponds to the strength of current it is delivering, while the voltage of the second generator is that corresponding to a zero current. Now the voltage will drop as the current increases, and will rise as the current decreases; hence, when the second machine is cut in, the voltage of the first one will increase, for now there are two machines to develop the same current; therefore, the current in the first one will be reduced, thus causing its voltage to rise.

While the voltage of the first generator will increase, that of the second one will drop, because the current generated by it will increase. We stated above, that the second machine is adjusted so that its voltage is slightly higher than that of the first one, before it is cut into the circuit, and as can now be understood, we make it a little higher so as to compensate for the rise in the voltage of the first generator, as well as the drop in that of the second. In making this allowance, however, we have to use our judgment as to what it should be and it is not likely that we shall hit the nail exactly on the head every time; so, in the majority of cases, we have to make a second adjustment after the two machines are connected with the circuit.

When the generators are stopped, both must be cut out of the circuit, for if they are left connected, trouble may result when the next start is made. In addition to this it is not safe to stop the machines without cutting them out of the circuit, even if both are run by the same engine. If we desire to stop one of the generators, the only proper course is to open the switches *S S* before the engine is stopped. If this is not done, as soon as the speed of the generator that is being stopped reduces a trifle below the normal, its voltage will be so far reduced that current from the other generator will run back through it, and thus drive it as a motor.

This is also the reason why it is necessary to disconnect both machines when they are stopped; for if they are left connected, then in starting up the next time one machine may pick up its voltage sooner than the other one and current from it will not only pass out to the line but would also drive the other machine as a motor.

Another reason why it is necessary to cut the generators out of the circuit when they are stopped is that if they are connected, they may not be able to "pick up the current," as it is called. This is true even when only one machine is used. The reason why the machine may not pick up the current is that the external circuit may be closed through a low resistance, so that the machines will have to start under a full load, and under such conditions, generators will not always build up electromotive force.

Suppose a generator is started with the main circuit closed,

and that the resistance is so low that the maximum current could be driven through it with the full voltage, then the current flowing through the armature with a small voltage would be quite strong. Now there is always a small amount of magnetism left in the fields of a generator, and this is sufficient to develop a small voltage, which will drive a comparatively strong current through the main circuit, but the current that it will force through the field coils will be next to nothing, as these have a high resistance. The result of this difference in the strength of the armature and the field coil current would be that the magnetism developed by the field coils would be insignificant, while that developed by the armature would be so far in excess of it as to completely overpower it, and thus prevent the machine from building up.

As a rule, when the current stops, all the devices in the circuit that are operated by it are cut out, so that if a generator were started with the *S S* switches closed, the chances are that it would pick up, but it might happen that all the devices were connected with the circuit, and then the result would probably be different.

When the generators are compound wound, the connections with the circuit are made as in Fig. 155. As will be seen from this diagram, the only difference between shunt and compound wound generators is that the latter have an additional set of field coils. We say set, because in these diagrams, the coil *M* represents all the shunt coils on the field, which may be one or two or even more, in a two-pole machine, while in a multipolar generator they would be equal in number to the number of poles. The coil *M* represents what are called the series, or compounding coils, and these will be the same in number, as a rule, as the shunt coils.

Examining these diagrams of the generators in Fig. 155, we shall find that the *M* coil is connected in the same way as in Fig. 154, but the *m* coil is so connected that all the current generated in the armature passes through it and thus the field is magnetized by the combined action of the two coils *M* and *m*.

It will be noticed that from the point *a*, where the shunt coil connects, a wire runs down to the switch, and when this is closed, point *a* is connected with bus *E*. This is the connection for both

generators. From the end of the series coils *m*, a wire *d* runs to the switch, and through it connects with bus *B*, while the wire leading from the right-side armature terminal is connected through the switch with bus *D*. The bus *E* is called the equalizing bus, and the wires which connect it with the point *a* are called the equalizing wires, or connections. The object of these connections, and the *E* bus, is to assist in keeping the currents of

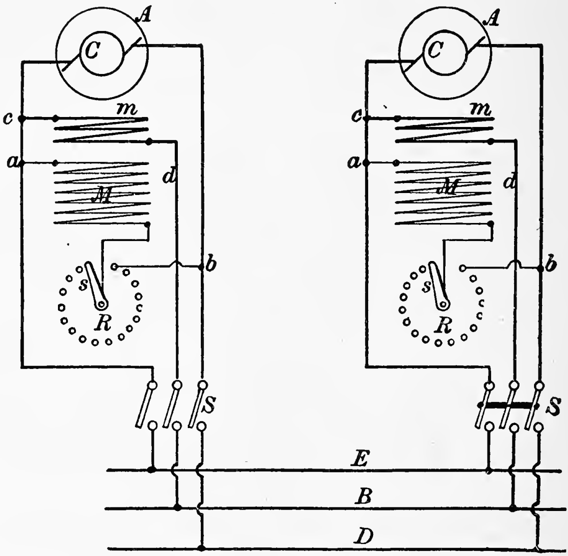

FIG. 155.

the generators equal. The way in which they accomplish the result can be made clear by the aid of Figs. 156 and 157.

These diagrams are drawn to show the connections of the armature and the series coils *m m* only; the shunt coils being left out so as to simplify the drawing. Fig. 156 shows the connections just as they are in Fig. 155, while Fig. 157 shows them as they would appear if the equalizer bus and connections were not used. By examining Fig. 155 it will be seen that the effect of

the connection through the equalizing bus is to connect the points *a* of the two machines and this is what Fig. 156 accomplishes in a simpler manner.

Suppose that in Fig. 156 the armature on the left side generates 40 amperes, while the one on the right generates 20, then the sum of the two currents will be 60 amperes, and this will pass through wire *c*. Now the current on leaving *c* will divide through the two *m m* coils in amounts that will be in proportion to the resistances of these coils. If both coils have the same resistance, each one will take half the current, that is 30 amperes. Thus we see that while one of the armatures generates 40 am-

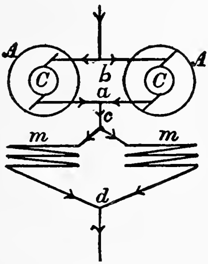

FIG. 156.

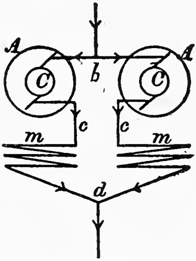

FIG. 157.

peres and the other one 20, the currents passing through the two *m m* coils are of the same strength, namely, 30 amperes.

If the connections were as in Fig. 157, it can be seen that the currents through the *m m* coils would not be equal but would be the same as those through the armatures; that is, one would be 40 and the other 20 amperes. Now, under the latter conditions, the armature generating the stronger current would have its field magnetized to a greater extent by the action of its *m* coils, and thus its voltage would be increased so as to further increase the current; while the generator developing the weak current would have its field strengthened to a lesser degree by its *m* coils; hence, the effect of these coils, if connected as in Fig. 157, would be to magnify the irregular action of the machines, so that if one tended to do more than its share of the work, the increased effect of its *m* coils would cause it to do still

more. By using the equalizing connection of Fig. 156, the *m* coils act to equalize the action of the generators, for no matter what the strength of the current through the armatures may be, it will be equally divided through the field coils *m m*.

In starting compound generators, one is connected with the circuit first, just as with shunt machines. Then the second machine is started and adjusted so that its voltage is slightly lower than that of the first machine. This being done, the left-hand switch *S* is closed, so as to make the equalizing connection. The next switch to be closed is the center one, which places the *m m* coils of the two generators in parallel relation just as in Fig. 156. When this connection is made, the voltage of the first machine will drop slightly, and that of the second one will increase, for as soon as the connection is made, the current passing through the *m* coil of the first generator will be reduced to one-half its strength, thus slightly reducing the strength of the field, while through the *m* coil of the second machine the current will increase from zero to the same strength as that flowing through the *m* coil of the other generator, thus increasing the voltage of the second machine.

We now close the right-hand switch and thus completely connect the second machine with circuit. If the two machines are not now taking their proper shares of the load, we adjust the rheostats so that they do, by increasing the resistance in the circuit of the shunt coils of the one that is doing more than its share, or reducing the resistance in the other.

In stopping, if the switches are separate, they should be opened in the reverse order to that in which they are closed; that is, the one that is closed last should be the first one to be opened. As in the case of shunt generators, the machines should be started before they are connected with the circuit, and must not be adjusted until running at full speed; and in stopping they must be cut out of the circuit before the engine is stopped.

CHAPTER XXXII.

Changing the Voltage of Generators.

GENERATORS such as are used to furnish current for incandescent lamps are called constant potential generators from the fact that they maintain the voltage, or potential constant regardless of how the current strength may vary. As a matter of fact, they do not keep the voltage absolutely constant, but the variation is so slight, in well-regulated machines, that for all practical purposes it can be regarded as constant.

Constant potential generators are made either shunt or compound wound. A simple shunt generator has its field magnetized by coils that are connected in shunt relation to the armature. A compound generator has its field magnetized by two sets of coils, one being in shunt to the armature, and the other in series with it. The shunt coils are made of many turns of fine wire, and the series coils are made of a few turns of large wire. Fig. 158 shows the way in which the shunt field coils and the armature are connected in a simple shunt generator. In a compound machine the only difference is that the armature current instead of passing directly to the line wires *L L′*, first passes through coils of wire wound upon the field magnets.

Constant potential generators are made so as to develop a certain voltage at a certain speed, but it is a very difficult matter to so proportion a machine that it will give the required voltage at exactly the speed desired. For example, if we start out to make a generator that will develop a voltage of 115 at one thousand revolutions per minute, we may find upon testing it that the speed required to give this voltage is 983 revolutions per minute. The next machine made from the same patterns, and as nearly a duplicate of the first one as possible, may require a speed of 992 revolutions per minute to develop the 115 volts.

It would not be desirable to mark each machine at the exact speed required, because there would be no uniformity; therefore, a field regulator is provided by means of which the voltage can be adjusted within certain limits and, with this, the gener-

ator can be run at one thousand revolutions per minute and the voltage will be 115. In Fig. 158 the field regulator is shown at *B*. This regulator is simply a resistance which is provided with a switch by means of which more or less of the resistance may be cut in or out of the field coil circuit. It varies the voltage of the machine by increasing or decreasing the strength of the field current.

Generally field regulators are made of such capacity that,

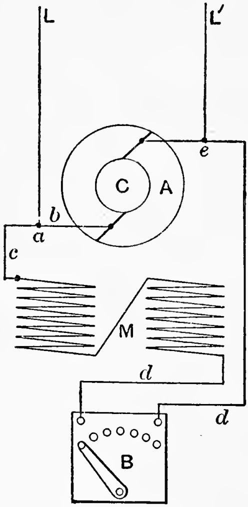

FIG. 158.

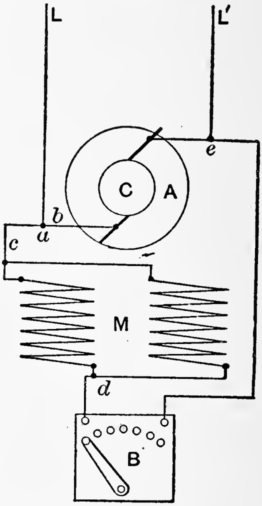

FIG. 159.

by inserting all the resistance in the circuit, the voltage can be reduced from 10 to 15 per cent, and in small generators, even as much as 25 per cent. This range of adjustment is provided because it is not always practicable to run the machine at the proper speed. Thus, if it is rated at 1,000 revolutions per minute, it may not be possible to run it any nearer to this mark than 950 without going to the expense of getting new pulleys. This reduction in speed would lower the voltage from 115 to about 109; but if the field regulator is of large capacity, the generator will probably be able to develop the full voltage at even a lower

velocity than 950, for the machine is likely to be so proportioned that it will give the rated voltage at the rated speed with about one-half the field regulator in service. If the machine has to be run above the rated speed, the voltage can be cut down by inserting more of the field regulator resistance.

From the foregoing it will be seen that any generator can be adjusted to give a somewhat higher or lower voltage than that at which it is rated, by simply setting the field regulator. If we desire a higher voltage we cut out resistance; and for a lower voltage we add resistance. A further variation in voltage can be obtained by changing the speed of the generator, but a very great reduction in the voltage cannot be so made because, if the reduction is too great, the voltage will be so low that it cannot force through the field coils as much current as is necessary to cause the machine to act.

By increasing the speed the voltage is increased and the more the speed is increased the higher the voltage; so that the increase in voltage by increasing the speed is only limited by the speed that is practicable and by the strength of current that the field coils can carry without burning out. If the voltage is increased, the current through the field coils will be increased, so that the increase in voltage will be greater than the increase in speed, from the fact that we shall have an armature running at a higher speed in a stronger field. Owing to this fact, the increase in voltage will not be limited by the speed at which the armature can be safely run, for long before this speed is reached the strength of the current flowing through the field coils will be all that they can safely stand.

Without changing the speed of the armature, the voltage of the machine can be increased by connecting the field coils in parallel, as in Fig. 159. With this connection the strength of current passing through the field coils will be doubled, and if the wire will stand this increase without overheating, the voltage of the machine, at the same speed, will be increased 20 to 70 per cent, according to the density to which the field is magnetized with the regular connection of the field coils. If the coils cannot carry the increased current without overheating, an additional resistance can be connected in the circuit; that is, the resistance of the regulator *B* can be made greater. If this additional re-

sistance is not at hand, the speed of the armature can be reduced until the field current becomes weak enough not to injure the coils.

In the foregoing, several ways of changing the voltage of a generator are shown, but it will be noticed that in every case the variation is not very great, and it may be said that in general, it is not practicable to vary the voltage more than 70 per cent without reconstructing the machine; that is, if the normal voltage of the generator is 100 it cannot be increased to more than 170, and it cannot be reduced to less than 60 volts.

As multipolar generators have four or more sets of brushes,

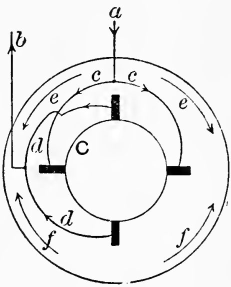

FIG. 160.

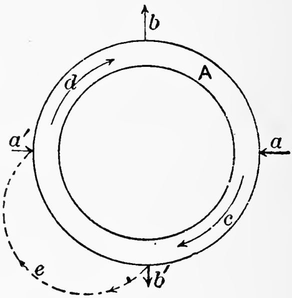

FIG. 161.

it has been assumed by some inexperienced men that by properly connecting these brushes, the voltage could be varied through a wide range. Such is not the case, however, and an attempt to make changes in these connections may lead to serious results. We will show why the desired result cannot be accomplished, and also what the actual result is liable to be.

In Fig. 160 the armature and commutator of a four-pole machine are shown diagramatically. The outer circle represents the armature, and the inner circle *C* represents the commutator. The four brushes of such a machine are connected with each other as shown, the two side brushes with line wire *a* and the top and bottom brushes with wire *b*. The current entering through *a* follows the connecting wires *c c* to the side brushes,

and after traversing the armature passes through the wires *d d* to line wire *b*. The path of the currents through the armature is indicated by the arrows *e e* and *f f*, and from these it will be noticed that each current flows through one quarter of the armature wire only.

Now, it is natural to suppose that, if we were to connect the brushes in the way indicated in Fig. 161, the current entering through brush *a* would follow the path of arrow *c* and come out through brush *b′*, and that, if it were then conveyed to brush *a′*, by means of a connection *e*, it would once more pass through the armature along the path indicated by arrow *d*, and

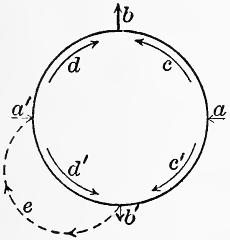

FIG. 162.

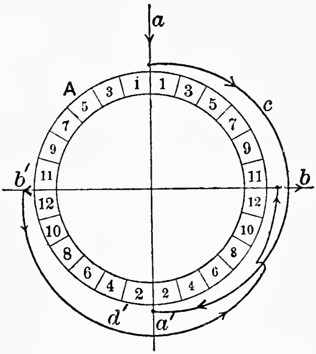

FIG. 163.

come out at brush *b*. If the current would follow this path, its voltage would be doubled, for the voltage developed in the path *d* would be equal to that developed in path *c*. The difficulty in the way of realizing this result is that the connection *e* not only enables the current generated in *c* to pass to brush *a′*, but also enables that generated in the quadrant spanned by *e* to return upon itself, as shown in Fig. 162. In this diagram it will be seen that the current generated in quadrant *d′* flows from *a′* to *b′* and thus the connection *e* simply serves as a short circuit for this portion of the armature; and a large machine with this connection would soon be disabled, as the heat developed in the

short-circuited portion of the wire would heat it to the burning point in a few minutes.

Armatures can be connected so that the electromotive forces generated in the several sections are added to each other, and when so connected they are said to have a series, or wave winding. But an armature wound so that the several e.m.f.'s are not added, cannot be made to give a higher voltage by changing the brush connections. The way in which armatures are connected for series or for parallel winding is illustrated in Fig. 163. If the armature is parallel-connected, or lap wound, as it is called, the current entering through wire *a* will pass through the coils 1, 3, 5, 7, 9 and 11, in both the upper quadrants; and through the connecting wire *c* it will reach brush *a'* and then flow through the coils 2, 4, 6, 8, 10 and 12, and in this way the currents will reach the side brushes *b b'* after traversing one-quarter of the number of coils on the armature. This is the case with a four-pole armature; with a six-pole the currents would pass through one-sixth of the number of coils, and so on for a greater number of poles.

If the armature is series-connected, or wave wound, the current from *a* will pass through coil 1, and then by a cross connection (not shown in the diagram) will reach coil 2, and from the end of this coil by another cross connection will return to coil 3, from which it will pass to coil 4. Thus the current will cross from one side of the armature to the other until it reaches coil 12, from which it will pass to brush *b'*. With this winding the connection *c* carries a part of the current to brush *a'*, from which it enters coil 2 and follows the same path as the current entering at brush *a*. The only object of the connection *c* is to provide more brushes through which the current can enter and pass out, and thus prevent the undue heating of the brush ends. If the connection *c* is removed and also the brushes *a'* and *b*, the action of the machine will not be interfered with in the least.

In a series-wound armature the path of the current may be better illustrated by Fig. 164, but to properly understand this it must be remembered that the current does not pass through all the coils in the quadrant *c* and then through all those in quadrant *e'*, but through one coil in one quadrant and then through a coil in that opposite, and finally reaches the brush *b*.

While a series-wound armature can be run with two brushes and deliver its full current, a parallel-wound armature, if used with two commutator brushes, will deliver only a portion of its full current. This can be understood from Fig. 165, in which,

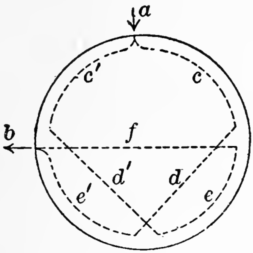

FIG. 164.

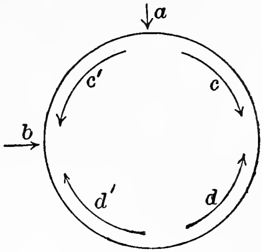

FIG. 165.

as there are only two brushes, *a* and *b,* the currents generated in the sections *c* and *d* have no outlet, and as the e. m. f.'s are in opposition to each other, they neutralize each other, so that only the current generated in section *c'* finds an outlet.

CHAPTER XXXIII.

Grounds and Field Short Circuits.

WHEN the insulation between an electric circuit or machine and the ground becomes impaired, so that an electric connection is made with the ground, the circuit or machine is said to be grounded. If the electrical connection so established is perfect it is called a complete or dead ground, and if the connection is imperfect it is called a partial ground. Overhead line wires become grounded by rubbing against limbs of trees through which they pass or against the walls of buildings into which branch connections are run, and in various other ways.

Line wires are, as a rule, covered with an insulating envelope, and to form a ground this covering has to be rubbed away by the chafing of the wire against the surface with which it comes in contact. In underground wires, ground connections are formed by the impairment of the insulating covering, either by the shifting of the wires, by the chemical action of gases, or by injuries inflicted by workmen when digging in the vicinity of the conduits.

One ground in a circuit will cause no damage, because the current cannot escape through such a leak unless there is another connection through which it can get back into the circuit. All the current that passes out of the generator through the positive wire must return to it through the negative; therefore, no current can leave the circuit proper, at one point, unless it can find its way back at some other point.

Although a single ground can do no damage, it is inadvisable to permit it to exist, for it is always possible for the second ground to form when least expected; and as soon as it does, there will be more or less serious trouble, according to the positions of the two grounded points. Tests for ground connections can be made in a simple manner, and in every case, where the distributing lines run any distance and specially if so situated that there is a decided liability of their being injured, tests should

be made every day. The apparatus required for making such tests is to be found in any place where a generator is installed, and it can be put in proper position in a few hours; after it is once installed the daily tests can be made in a few minutes.

For ground testing, the general arrangement of apparatus is illustrated in Fig. 166, in which $L L'$ represent the bus bars on the switchboard, or if there is no switchboard, as may be the case in a small plant, they may be taken to represent the main distributing wires, from which the branch circuits are taken. A represents the armature and M the field of a simple shunt-wound generator, R being the field regulator. B is the main switch for connecting the generator with the line wires. If the generator is compound wound it will make no difference in the connections of the ground detecting apparatus. From the wires leading from the generator to the main switch B, two wires, $d\ d$, are run to contacts $e\ e'$, of a small switch s, which latter is connected with one of the terminals of an incandescent lamp l. The other terminal of this lamp is connected with the ground as indicated at G. To make this ground connection, the wire can be attached to a water pipe, care being taken that a good metallic contact is obtained.

To find whether there is a ground in any part of the entire circuit, the main switch B is closed so that the current of the generator may feed into the working circuit. From this it will be understood that the test is to be made while the machine is running and feeding the circuit. The small switch is now moved so as to connect with e, and then so as to connect with e'. If when in either position the lamp l does not light up, we know that there is no ground in any part of the circuit; at least, no ground sufficiently bad to permit a current of any magnitude to pass through it.

If the generator delivers a current at an e. m. f. of 110 volts, we can determine the existence of even imperfect grounds by substituting for the single lamp l several lamps of much lower voltage, their combined e. m. f. being 110 volts. Thus we could use two 55-volt lamps or four 25-volt lamps, these being connected in series, so that the current would pass through all of them, one after the other. Each one of these lamps should be provided with a small switch to short-circuit it.

With this arrangement of a number of lamps in series, we first close the switch *s*, with all the lamps in the circuit, placing it on *e*. If the lamps do not light up, we cut out one, and if the others still remain dark, we cut out another one, and so on until only one lamp is left in the circuit. If with this single lamp in service no light is produced, we then cut all the lamps back into the circuit, and move switch *s* to contact *e′*, and repeat the test.

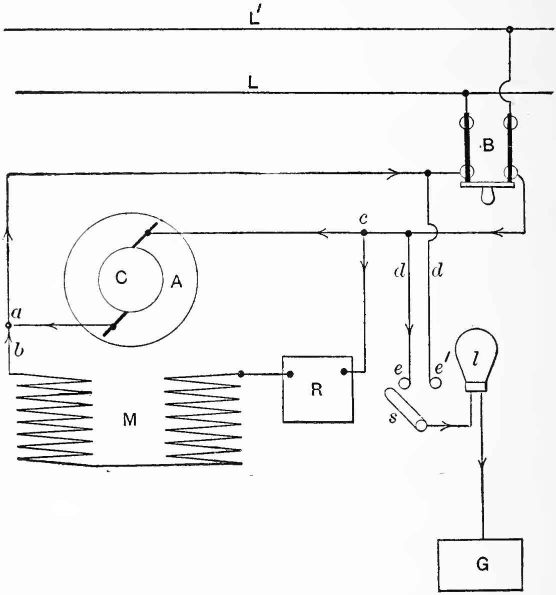

FIG. 166.

In this way an imperfect ground can be detected, because while the leakage current may not be sufficient to light up a single 110-volt lamp, it may be capable of producing at least a visible light in a 55 or 25-volt lamp.

Two wires, *d d*, are used to enable us to determine on which side of the circuit the ground is located. Suppose that there is a ground on the main *L*, or on one of the branches leading from it; then, since the contact *e′* is connected with *L*, it follows that,

if switch s is placed on e', only a small current will pass through the indicating lamp l; for it will be only that due to the slight difference in resistance between the ground connection and the portion of the line L between the generator and the point where the ground is located. If now we move switch s to contact e, which is in direct connection with L', the whole voltage of the circuit will act to force a current through the lamp l. From this it will be seen that, if the lamp lights up when s is on e, we know that the ground is on the L side of the circuit, but if the lamp lights up with s on e', we know that the ground is on the L' side.

After finding that there is a ground in the circuit, we can determine whether it is in the distributing lines or in the generator by opening the main switch B, for if upon opening this, the lamp l fails to light up, we know at once that the ground is beyond B. On the other hand, if opening switch B does not affect the lamp l, we know that the ground is in the generator or the connections running from it to B.

If the machine is a motor instead of a generator, we can test for ground connections by the same arrangement, but in this case the wires $d\,d$ are to be connected with the line wires $L\,L'$, so that we may be able to test the line for grounds before the motor is connected. To connect the wires $d\,d$ with the line wires $L\,L'$ all that is necessary is to run them to the upper binding posts of the main switch B.

To test the line for ground, the switch B is opened, and then switch s is placed on e and e' in the manner already explained. If we find that the line wires are clear, the switch B is closed and the test is repeated, and if it shows a ground we know that this is located in the motor or in the connections between the motor and the main switch B.

If we now disconnect the field wires of the motor, as is illustrated in Fig. 167, and insert a resistance R in the armature circuit, we can find whether the ground is in the armature by connecting one terminal of a voltmeter with one of the commutator brushes, and the other with the field frame, or with any of the metallic portions of the motor as indicated at c. If this test shows the armature to be clear, we disconnect the wires from the brushes and connect them with the field terminals and

then repeat the test. If this second test shows that the field coils are sound, then we know that the ground is in the connecting wires.

Voltmeter *V* in these tests can be replaced by an incandescent lamp, in the same manner as the lamp in Fig. 166 can be replaced by a voltmeter. If a voltmeter is used in either test, it should be capable of indicating as high an e. m. f. as that of the line current, otherwise the instrument may be seriously

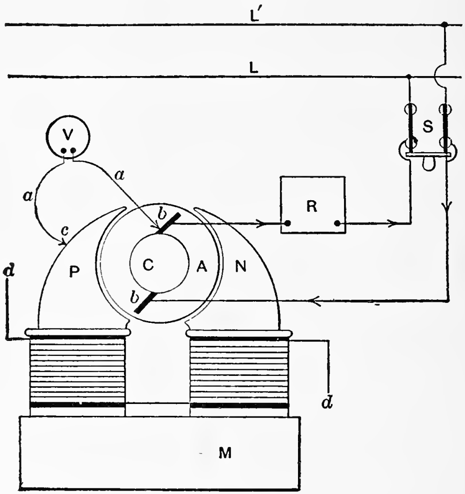

FIG. 167.

damaged by the current that will flow through it if there is a complete ground.

If a resistance for *R* in Fig. 167 is not at hand, we can get along without it by testing the field coils separately, and then disconnecting the connecting wires from the motor and testing each one of these independently. In testing these connecting wires, we must be careful not to connect their ends, for if we do, the main line will be short-circuited the instant switch *S* is closed, and the results may be serious.

Sometimes a motor or generator may not run well on ac-

count of a ground connection in the field which will allow a portion of the current to be diverted from its proper channel. If there is a ground in the armature, it is likely to produce such a disturbance as to render the machine practically useless, and if it is allowed to run, the leakage through the ground will soon end in a destructive burn-out, which will require rewinding the armature. Grounded armatures can seldom be repaired before they are burned out, but such is not the case with grounded field coils.

If, without any apparent reason, the brushes begin to spark badly, yet are found to be in proper adjustment, we may infer that there is some defect in the field coils, either a ground or a short circuit. By the method just explained we can determine whether there is a ground, and by the process illustrated in Fig. 168 we can ascertain whether there is a short circuit. This diagram represents a four-pole machine, which may be either a motor or a generator. A voltmeter connected with the mains L L' will indicate the full e. m. f. of the circuit, and if there are four field coils, as in the figure, a voltmeter connected with the ends c a' of one of the coils, as shown, should show a voltage equal to one-quarter of the total. If each coil is tested separately, the one which is short-circuited will show a lower voltage than the others, and in this way we can pick out the defective coil. This test is to be made while the machine is running. Sometimes, tests of this kind cannot be made with the machine in operation. This is generally the case with generators.

If a generator armature is short-circuited, it can be run only a few seconds before it will be burned out. If any of the field coils are short-circuited the machine can be run, but the sparking at the commutator is liable to be severe. On that account the tests for field defects, grounds as well as short circuits, are better made with the generator at rest, in which case it is necessary to use a battery to provide the testing current, and as the voltage of this is not sufficient to give on a voltmeter any reading that can be of service, it is necessary to substitute for the voltmeter a galvanometer; an ordinary detector galvanometer will answer the purpose. The most satisfactory kind of battery is the dry cell which can be obtained in any electrical supply store at a very low cost.

If the galvanometer needle swings around more than 60 degrees when connected to test a field coil, a resistance should be placed in series with it so as to reduce the angle of deflection. In making the test in Fig. 168, the battery is connected with the mains *L L′* and the galvanometer takes the place of the instrument *V′*. The number of cells of battery connected with

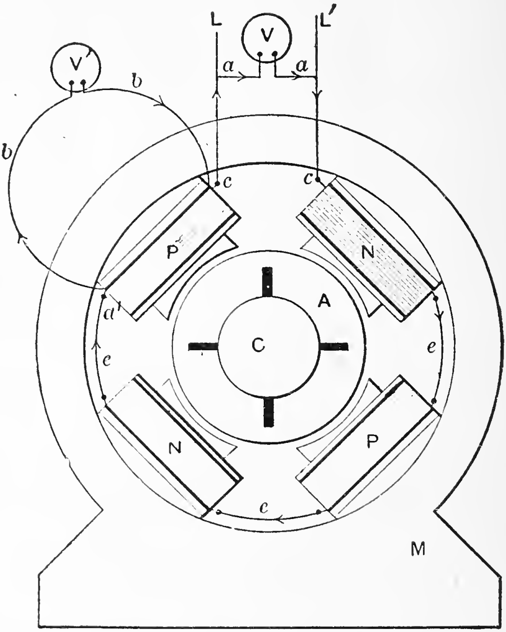

FIG. 168.

L L′ will depend upon the resistance of the field coils, and can be easily determined by actual trial. If one cell gives a very small deflection of the galvanometer needle, say 10 degrees, try two cells connected in series, and then three, until the deflection is somewhere between 45 and 60 degrees. If one cell gives too great a deflection of the galvanometer needle, use a resistance in series with the instrument to cut down the current

passing through, thus reducing the deflection of the needle. If all the field coils are sound, the galvanometer needle will be deflected the same amount when each one is tested, but if one of the coils is short-circuited, the deflection of the needle produced by it will be smaller.

If the short circuit does not include the whole coil, the reduction in the deflection of the needle will be only a few degrees, but if the short circuit is from end to end of the coil, the deflection of the needle will be reduced to nearly nothing; thus, by the amount that the deflection of the needle is reduced, we can judge as to how much of the coil is short-circuited.

When the field coil that is short-circuited has been located, the next step is to find the defective points. This can generally be done because, at the defective points, a sufficient amount of heat will be developed to char the insulation and cause it to give out the odor of burned shellac. If the damage cannot be repaired without defacing the coil, which will most likely be the case, as the short-circuited points are almost sure to be below the surface, then rewinding is the only proper remedy.

Temporary repair can be made by removing the wire from a portion of the coil, as is illustrated in Fig. 169, holding the rest in position by means of wooden blocks. As each layer is removed, the ends of the wires on both sides of the opening are tested, and when the layers that are short-circuited are reached, the test will show that they are connected with each other—that is, if one of the ends of the wires from the galvanometer is connected with the end of one layer or wire on the coil, and the other end is connected with another layer, and the needle moves, then we know that these two layers of wire are short-circuited.

After all the short-circuited layers have been picked out in this way, the perfect layers can be reconnected, being careful to connect the ends that wind right sided with those that wind left sided; and also being careful that all the layers are connected in series. This latter result can be accomplished by connecting one of the wires from the galvanometer with the end of the top layer of the coil; then with the other end of the galvanometer wire, the other end of the top layer can be found. This is to be connected with any end that winds in the opposite

direction, and the remaining end of this second layer can then be picked out by the aid of the galvanometer, in precisely the same way that the remaining end of the top layer was found. This end is in turn connected with another end that winds in

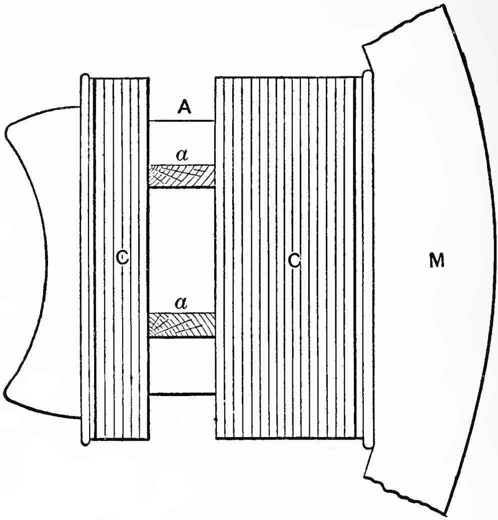

FIG. 169.

the opposite direction, and thus the connecting is carried on until all the layers that are perfect are joined up.

The machine will not run perfectly when patched up in this way, but unless a large number of turns have been rendered useless by the short circuit, it will work well enough for temporary use, until a permanent repair can be made.

CHAPTER XXXIV.

Repairing Short Circuits in Armatures.

DIRECTIONS for finding short circuits in the armatures of generators are not necessary, as in almost every case they find themselves; and the first notice we get of the fact is that the machine gives off a very strong smell of burning shellac, which is immediately followed by smoke and, possibly, some flame. After this the generator is useless until the armature is rewound. In some cases, the short circuit is only partial, and then the only way that its presence can be detected is by the odor peculiar to hot shellac. This is a condition that is seldom encountered, for even if the short circuit is imperfect at the start, when it reaches the point where the armature begins to heat up, it progresses so rapidly that, before we know what has occurred, the wire is burned out.

When a short circuit forms in the armature of a generator, it affords a path of comparatively low resistance through which a portion or all of the current can circulate, according to the position of the points between which the short circuit is effected. If the contact at these points, between the metallic parts of the circuit—that is, between the bare wires—is not very good, the resistance may be so high as to permit only a small current to pass; but this current will heat up the points of contact, and as a rule will result in making the connection more perfect, either by charring the small amount of insulating material between the wires, or by expanding the metal until the two parts come into more perfect contact.

Whichever way the action may proceed, the result will be that the resistance in the short circuit path will be reduced and the current increased, and as the action progresses, the change in resistance and current strength becomes more rapid, until a point is reached where the heat generated is enough to make the shellac smell; only a few seconds more will be required to develop sufficient heat to burn the insulation and perhaps fuse the wire. Thus it will be seen that in generators, short circuits

come almost without warning, and it is almost never that warning is given in time to save the armature from destruction.

With motors, however, the case is quite different. As a rule, if a motor armature is short-circuited it will not rotate when the current is turned on, even if the machine is running light. If it is helped by hand, it may rotate slowly, but with an irregular, jerky motion. In most cases, however, when turned by hand it will make a portion of a revolution and will then come to a standstill. In order to move it from the position in which it stops, a considerable effort will be required; but as soon as it has been carried beyond a certain point it will immediately swing forward of its own accord, and again come to a stop at the first position.

If short-circuited, a motor armature will not be burned out because it cannot rotate, since there is no electromotive force other than that of the supply circuit to force a current through the short circuit, and the supply current is controlled by the resistance of the starting box and the safety fuses or circuit breakers, whichever may be used, so that it cannot rise above a safe strength.

It is not a difficult matter to find the position of the short-circuited coils in a motor armature, but to find the exact position of the points of contact is, in most cases, rather difficult without removing some of the wire. By the aid of the accompanying diagrams we can illustrate the means that may be employed for locating short circuits.

In Fig. 170 the circle *C* represents the commutator of a motor armature and *V* is a voltmeter. This diagram represents a two-pole machine, for which two commutator brushes are required. The current enters through the upper brush and passes out through the lower one. From the segment of the commutator on which the upper brush rests, the current passes in two circuits through the armature coils until it reaches the segment on which the lower brush rests. After passing through each armature coil, the current reaches the wire that connects with the corresponding commutator segment, so that we may say that these connecting wires are reached progressively on each side of the commutator, in the manner indicated by the arrowheads on circle *C*.

Now, to force the current through the armature wire requires a certain electromotive force. Suppose that the armature is held so that it cannot rotate, and that one wire from the voltmeter *V* is connected with the upper brush, while the other wire is connected at different points on the surface of the commutator, as indicated at *c*. If the point of contact *c* is near to the upper brush, say the width of one segment, then the voltage indicated by the voltmeter *V* will be that required to force the current through one of the armature coils. If the point *c* is now advanced to the second segment, the voltmeter will indicate the voltage required to force the current through two armature

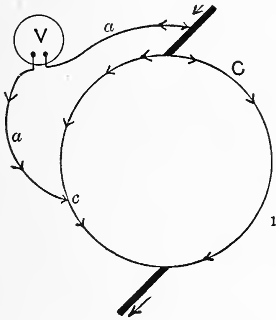

FIG. 170.

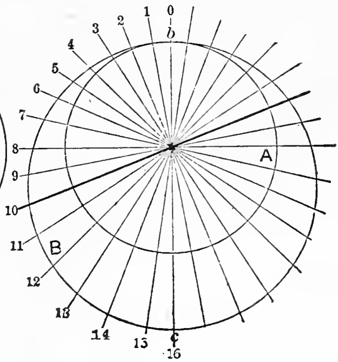

FIG. 171.

coils. In the same way, if the point *c* is advanced to the third segment, the voltmeter will indicate the voltage required to force the current through three coils, of the armature wire.

If we draw a diagram such as Fig. 171, which consists of a circle, *A,* and a number of radial lines, 1, 2, 3, 4, etc., equal to the number of segments in the commutator; and if on these lines we mark off distances extending outwardly from the circle, equal to the voltage indicated in the instrument *V* with the point *c* in the corresponding position; then, by tracing through the marks so obtained a curve, *B,* we shall have a representation on paper of the manner in which the voltage rises, as the

point *c* in Fig. 170 is advanced from the upper brush toward the lower one.

This curve will show us the voltage required to force a given current through the armature wire from the point where the upper brush connects with it to the point where *c* makes contact. If the armature is not short-circuited at any point, the resistance of all the coils will be practically equal, and as the voltage required to force a current through a resistance is equal to the current strength multiplied by the resistance, it follows that, as the resistance is increased uniformly by adding coil after coil to the circuit between the upper brush and the contact point *c*, the voltage will also rise uniformly.

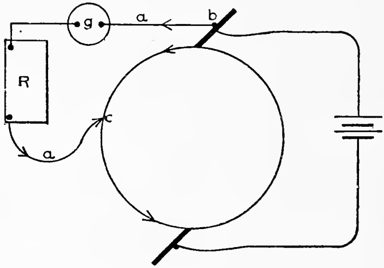

FIG. 172.

For making this test it is necessary to insert a large resistance in the armature circuit, so as to keep the current down to a safe limit. The motor starting box is of sufficient resistance, but it cannot be used for the purpose because the resistance coils are not of sufficient size to be kept in the circuit for more than a few seconds. The voltmeter used should be of capacity to indicate small voltages. It is not always possible to obtain a resistance suitable to be placed in the armature circuit, and likewise it is not always convenient to obtain a low-reading voltmeter—one that will indicate from 10 volts downward. We will, therefore, explain how this test can be made with a galvanometer.

For this purpose are required one or two dry battery cells, (which can be obtained in any electrical supply store at a cost

of 25 or 50 cents), a galvanometer of any kind, and a resistance, *R*, to place in the galvanometer circuit, as shown in Fig. 172. The resistance *R* is required because a very small current will produce a decided deflection of a galvanometer needle. The simplest form of galvanometer is known as a detector galvanometer, and good ones can be obtained for $2 to $3.

To test the armature with a galvanometer so as to obtain the curve *B* of Fig. 171, connect the two brushes with the terminals of the dry battery; then connect one terminal of the galvanometer with brush *b*, and the other terminal through re-

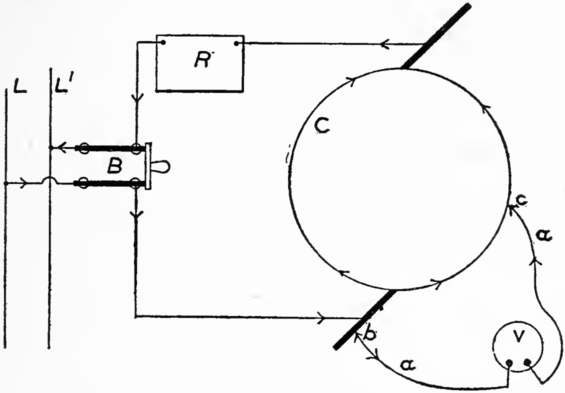

FIG. 173.

sistance, *R*, and the sliding contact *c* with the lower brush. Adjust the resistance *R* so that the galvanometer needle is deflected about 60 degrees, then move the sliding contact *c* back, segment by segment, and mark down, on a diagram prepared like Fig. 171, the degrees of deflection for each position of the contact *c*.

In this way a curve can be obtained which shows how the resistance varies from point to point between the brushes. It does not tell us the voltage required to force a given current through the wire, as does the test with the voltmeter, but that makes no particular difference. It may be well to mention that in using a galvanometer the instrument must be set level so

that the needle will swing freely, and also that it must be so placed that the needle points directly to the zero mark when there is no current passing through the instrument. In making a test with the voltmeter, as in Fig. 170, the armature is connected with the circuit in the manner shown in Fig. 173, with a resistance *R* sufficiently large to keep the current down to about the full-load strength.

In Fig. 171 the curve shown is regular like that for a perfect armature. It is not in correct proportion for such an armature, but it indicates the way that a test curve of a perfect armature would look.

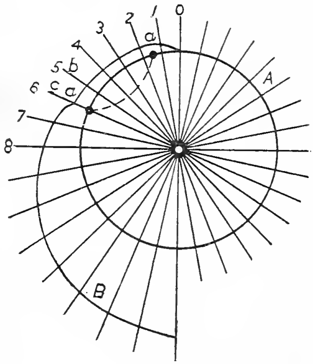

FIG. 174.

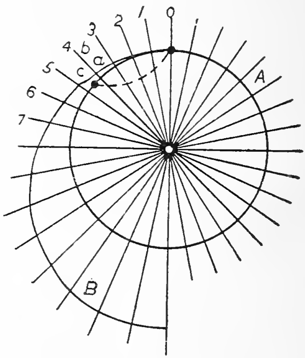

FIG. 175.

Now suppose that we test a short-circuited armature. Let the points that are short-circuited be located at *a a*, Fig. 174. Then in starting the curve, with the upper brush at *o*, the curve obtained would rise until it reached line 2 and the next measurement at position 3 would show but little rise in the curve. The voltage will be nearly the same until line 6 is reached. This shows at once that at *c* there is a direct connection with some point in the wire near line 2 which cuts out a large portion of the resistance.

To find out just where this point is, we revolve the armature one or two segments, and then test for another curve. Suppose that after several trials we obtain a curve such as shown

in Fig. 175, which rises hardly any until line 4 is reached, from this drop in the curve we realize at once that the segment at *c* is in a direct contact with the one from which we started the curve, for between these two points, the curve indicates practically no resistance; hence the short-circuited points *a a* are located one at segment *c* and the other at the segment at the top of the figure, on the line *o*.

If, in Figs 174 and 175, we were to continue to test the curve all the way around to the lower brush, we should obtain curves that would rise in a uniform manner as shown in these diagrams, provided there were no other short circuits in the armature; but if there were other short circuits, then for each one of these there would be a flat in the curve.

Sometimes an armature is short-circuited in several places; therefore, in making a test it is always advisable to obtain readings of the instrument for every position between the two brushes. If more than one short circuit is found, the segments with which they are all connected can be located by turning the armature around, one segment at a time, and making a test in each position so as to find those between which the rise in the curve is zero, as in Fig. 175 from *a* to *c*.

In making the foregoing test with a multipolar armature, the readings are taken for the number of commutator segments between two adjoining brushes, and the armature is advanced segment by segment and new readings taken to locate the short-circuited points. If the armature is parallel connected, the precise segments with which the short-circuited coils are connected can be located; but if the armature is series connected, the best we can do is to find the several segments that connect with the short-circuited coils. In a four-pole armature, there will be two segments that appear to be connected with each short-circuited point, if the armature is series wound; and in a six-pole armature there will be three segments apparently connected with each short-circuited point. By making a careful test the one of these segments that is the nearest to the point can be determined, as the others will give readings a trifle higher.

After the short-circuited points are located within certain armature coils, the next step is to see whether, by inspecting these coils, we can find the defective points. If the armature

coils are held in place by means of wire bands, we may expect to find the short circuit formed through one of these. If no defects can be found at these points, then we must endeavor to determine whether the coils cross each other at the ends of the armature and, if possible, ascertain whether the defect is located at these points. If we find that there is no defect at these crossings, then the only place in which it can be found is between the armature coils and the armature core, and both defective coils must be in contact with the iron core.

In some cases it is possible to find the short-circuited points without removing wire from the armature; therefore, in every case, effort should be made to locate the difficulty without unwinding the armature. If, at last, we find that the wire must be removed, we should start from points that will enable us to reach the short circuits by removing the smallest possible amount of wire. When the defect is uncovered, it may be found that it can be remedied by simply inserting a small piece of insulating material and without using new coils. When the defect can be found from an external inspection, in most instances the short circuit can be easily removed by slipping between the points in contact a sheet of some stiff insulating material. In most cases, a piece no larger than a postage stamp will be all that is required.

CHAPTER XXXV.

Finding and Repairing Broken Wires in Armatures.

BROKEN wires, or to speak more correctly, open circuits in an armature, are far more common in small machines than in large ones. On that account they are more often met with in motors than in generators, because the former are more common in the smaller sizes. The reason for more trouble with small machines is simply that the armature wire is smaller, hence more easily broken.

Broken wires proper are generally due to vibration produced while the armature is in motion. In some cases they may be due to defects in the wire which are not noticeable when the armature is being constructed, but such is not often the case. For one reason or another, there may be a flaw in the wire, and this will in time be developed into an actual fracture by the contraction and expansion due to the heating and cooling of the armature.

In ninety-nine cases out of a hundred, it can be assumed that the break is not due to a defect in the wire, but to the continual vibration to which it is subjected when the machine is running. The portion of the wire that is wound tightly against the armature core, cannot vibrate as much as that which is held loosely; hence, the proper places in which to look for breaks are in the portions of the wire that are held the least firmly. Of all these parts, the connections running from the armature coils to the commutator segments are the ones having the least support. Experience shows that in almost every case a broken wire will be found to be located in these connections, or directly adjoining them.

For breaks the most common place is at the point where the connection is made with the commutator segment. In some cases the wire will be found broken off at this junction, but more often the connection will be simply loose. In some machines these connections are made by means of screws, and in others the wire is soldered into the segments. Screw connections are quite liable to become loose, especially if the screw

presses directly against the wire, as is sometimes the case. If the wire is held between the end of the segment and a clamping cap, by means of two screws, there is less liability of the connection coming loose. Soldered joints, however, are the most reliable, if properly made, and are more generally used.

One advantage claimed for the screw connection is that, if the armature has to be disconnected from the commutator, it can be done with less trouble than with soldered connections. This advantage, however, is not of much account, if the machine is properly made, because it is only in case of a breakdown that the commutator has to be removed.

If there is a broken wire or connection in the armature of a motor, the machine will continue to run, but the severe sparking at the brushes will show to the attendant that something is out of order. In a generator of the two-pole type, a broken wire will stop the generation of current, but in a multipolar generator, a broken wire will not, as a rule, do so. As already stated, the presence of a broken wire in the armature of a motor can be detected by the sparking at the commutator brushes, which is also true with respect to multipolar generators. The spark produced by broken wires is of such a character that it can be easily detected by any one who has seen it before. When it is understood how a break in the armature circuit affects the operation of the machine, the appearance of the spark can be readily pictured in the mind's eye.

On an armature the wire is so connected as to form an endless loop, and the brushes are placed upon the commutator so as to make connection with this loop at points that divide it into two equal parts, provided the machine is of the two-pole type. For a four-pole armature there would be four brushes, and these would divide the endless loop into four equal parts, and similarly a six-pole machine would have six brushes that would divide the wire into six equal parts. The commutator is simply a sliding contact arrangement by means of which the connection between the brush and the armature wire may be shifted along as the latter revolves.

Commutator segments are connected with the ends of adjoining armature coils, so that when one segment slides under the brush and the next one behind it comes into contact, the

connection with the armature wire is shifted ahead the length of one coil.

If the armature wire is perfect—that is, without a break—the current passing in through the upper brush will divide into two equal parts, and one-half will flow through the one side and the other half through the other side of the winding; these halves will meet at the lower brush. Suppose, however, that there is a break in the wire, as indicated at *b* in Fig. 176. Then it is evident that the only path by which the current can reach the lower brush is through side *A*. If the current flowing through the armature has a sufficiently high voltage, it will be able to jump over the break at *b*, as indicated by the line *a*, and thus establish a path through the *B* side of the wire.

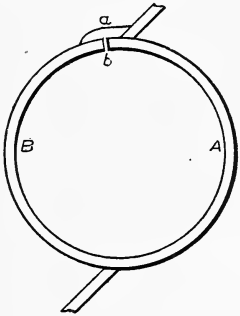

FIG. 176.

In an electric motor, this action actually takes place, and a spark leaps out of the end of the brush, as shown in Fig. 177 at *a*. If the motor is operated by a current of low voltage, say 110, the spark *a* may not draw more than ¼ or ½ inch, but with higher voltage it may lengthen out to 2 inches. In some cases, when the segments between which the break is located pass to some distance beyond the brush, the spark jumps from one segment to the other across the insulation, giving the appearance of a somewhat transparent ring of flame all the way around the commutator.

One most striking peculiarity of the spark due to a broken wire is its flickering in time with the rotation of the machine.

Each time the segments between which the break is located pass under the brush, the spark draws out, until the distance becomes so great that it breaks. As this drawing-out process is repeated at each revolution it causes the spark to flicker and this is accompanied by an intermittent noise, the noise and spark keeping time with the rotation of the armature.

If the break occurs in the armature of a two-pole generator, the machine will not generate, because the armature itself must supply the voltage that drives the current through the circuit, and as there is a break when it reaches the position of *b* in Fig. 176, the current will not bridge it, for the simple reason that the armature does not get a chance to build up a sufficient

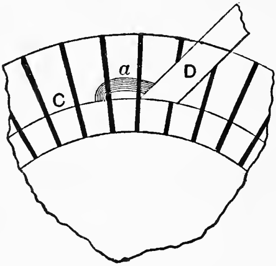

FIG. 177.

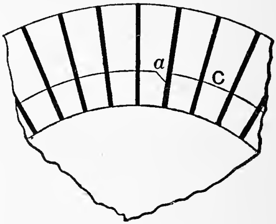

FIG. 178.

voltage, on account of the break. If the generator is of the four, six or eight-pole type, it will generate, because then the broken wire at *b* disables only one-quarter, one-sixth or one-eighth of the wire, and the remainder is sufficient to develop the necessary voltage to force the current over the break.

If an armature in which there is an open circuit or broken wire is run for a few seconds and then stopped, it will be found, upon examining the commutator, that in the case of a two-pole machine there will be one segment which has a corner badly burned away, as shown in Fig. 178. The segment diametrically opposite to this one may also show a slight burning, but nothing like as much as the one at *a*. If the machine is of the multipolar type there will be as many segments burned as there are pairs of poles, and these will be equally spaced all the way around

the circle. One of these, however, will be found to be burned more than the others, and to this one and to the segment back of it are connected the ends of the broken wire.

As already stated, if the machine is a two-pole generator, it will not generate with a broken wire in the armature, but from considering the action explained in connection with Fig. 176, it will be seen that if we could form the connection indicated in that figure by the line *a*, a current could be obtained, and such is actually the case. The simplest way of making this test is illustrated in Fig. 179, in which a strip of metal *a* is shown resting against the brush holder *D* with the end bearing upon the face of the commutator *C*. If the strip *a* is bent so that

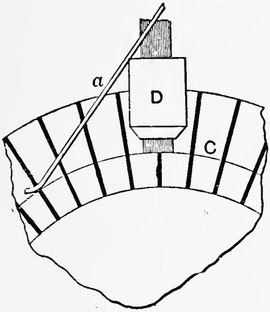

FIG. 179.

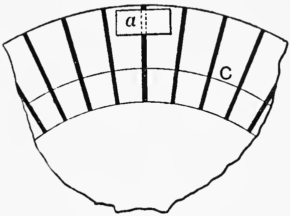

FIG. 180.

it can be made to bear upon the commutator some distance ahead of the brush, the machine will generate as long as the strip is in position. By running the armature for a few minutes with the strip in place, the segments connected with the defective wire will be burned and then, upon stopping the machine, the broken wire can be located.

Generally, when the broken wire has been located by the process explained, the disconnected ends can be easily found. In most cases the break will be simply a loose connection between the wire and the commutator segment. If this is not the cause of the break, the wire may be broken off just where it passes out of the shank of the segment. In either of these cases, the break can be easily repaired with a soldering iron. In some

cases, however, the broken ends cannot be found, and then the only remedy, short of disconnecting the armature and removing the wire until the ends are found, is to bridge the break, which is accomplished by simply making a connection between the segment *a* of Fig. 178 and the one back of it; that is, between the burned segment and the one back of it. This connection can be made by soldering a strip of brass to the two shanks, as shown at *a*, Fig. 180. Whenever this method of doctoring up the armature is resorted to, it is advisable to remove from the two connected segment shanks the ends of the coil in which the break is located; for it is possible for the break to be of such a character that it will mend itself, temporarily, when the machine is running. If it should, as the patch *a* forms a short circuit, the current developed in the coil would be very strong, and might heat the wire to such an extent as to damage the insulation of the adjoining coils.

This method of curing a broken wire, when the end of the break cannot be found, must be regarded as only a temporary expedient, and, as soon as possible, the armature should be taken out of the machine and, if necessary, the wire should be removed until the break is found and then repaired in a workmanlike manner. An armature doctored up in this way will run for any length of time and will continue to run even if a large number of breaks are bridged in the same way. In fact, the writer has seen armatures running with more than one-quarter of the commutator segments bridged, but the fact that the machine will run in this way does not prove that it is in perfect condition. As a matter of fact, it is far from it.

CHAPTER XXXVI.

Connection of Shunt-wound Motors with the Supply Wires.

TO MAKE these connections the proper way is shown in Fig. 181, in which *L L′* are the supply wires, *A* the motor armature and *M* the motor field magnet coils. At R is located a resistance, with a switch arranged to cut it out of the circuit, commonly called a motor starter. At *B* is placed a two-

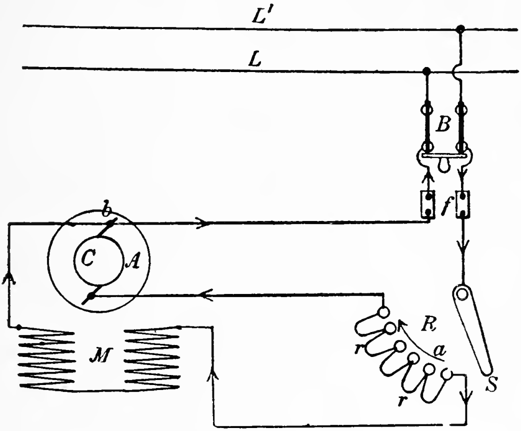

FIG. 181.

pole main knife switch and just beyond this safety fuses *f* are located.

One thing that may perplex the novice is, that while there are only two line wires *L L′* there are three wires, or binding posts, on the motor with which connections must be made, and there are also three binding posts on the motor starter *R*. An investigation of the motor will at once show that of the three wires, two come from the commutator brushes, and one from one end of the field coils. If the novice has good eyes, he will

soon discover that the other end of the field wire runs to one of the commutator brushes, as shown at *b* in the diagram.

It is clear that, if the three motor binding posts are all connected with the terminals of the motor starter *R,* there will be no way of making connections with the main switch *B*; therefore, all the motor wires cannot be connected with starting box connections.

Fig. 181 shows the proper connections for the type of motors commonly used to drive machinery, and which are operated by current derived from circuits that feed incandescent lights. This type is technically called a constant potential, shunt-wound motor. It is called constant potential because it is so designed that it will operate properly when supplied with a current of constant electromotive force—that is, a current whose voltage does not vary more than 3 per cent. It is called a shunt-wound motor, because the current that passes through the field magnetizing coils *M* is shunted from the main current, which passes through the armature.

In the diagram it can be seen that if the switch *S,* of the motor starter *R,* is turned to the left, so as to make connection with the first contact of *R,* the current can pass through the loops *r r* to the lower commutator brush and thus through the armature to the upper brush, whence it returns to the supply line. At the same time a separate current can flow from the first contact of *R* through the lower wire of the field coils *M,* and thus reach the main current at the upper brush *b.* From this it will be seen that the current that passes through the field coils *M* is shunted from the main line, so to speak, at the starting box *R,* and joins the line again at the upper commutator brush *b.*

For the field coils, the wire is fine, and of great length, and its resistance is so high that only a small amount of current can pass through it, the amount ranging from 5 per cent of the total in small motors down to 1½ per cent in large ones. The armature wire, on the other hand, is made quite large, so as to carry a large current without being overheated. In addition to being large, it is comparatively short, so that its resistance is very low—that is, it impedes the passage of the current to but a slight extent.

If the armature were held so that it could not revolve, and the two commutator brushes were connected directly with the wires from the main switch *B*, an excessive current would pass through the armature, possibly twenty or thirty times as strong as that required to develop the full power of the motor; this current would soon destroy the armature. When the armature rotates, however, there is a back pressure developed in its winding, which is called a counterelectromotive force, and acts to hold back the current, thus preventing it from increasing to an excessive value. The faster the armature revolves, the higher will be the back pressure.

In the starting box *R*, the loops *r r* are resistances, generally made of wire wound in the form of spiral springs. This resistance impedes the flow of current. When the motor is started, switch *S* is moved to the first contact of the motor starter, and then the current that passes to the armature has to flow through all the resistance loops *r r*, and thus is cut down to the proper strength. As soon as the armature begins to revolve, it develops a back pressure, and as this acts to cut down the current strength, it can replace the resistance in the starter *R*. As the speed increases, switch *S* is moved from contact to contact, and by the time the armature has attained its full velocity, all the resistance of *R* will be cut out—that is, switch *S* will be advanced to the last contact.

From the foregoing, it will be seen that the object of the motor starting box is to provide a resistance that can be inserted in the armature circuit, while starting, so as to keep the current strength down to a proper limit while the speed and back pressure are building up to their normal running values.

Safety fuses *f* are provided to protect the armature from the effects of excessive currents at any time. In starting, if switch *S* is advanced too fast, the current will increase too fast, as the back pressure developed will be insufficient to replace the resistance cut out of the series of loops *r r*. Safety fuses melt when the current is too great, and thus open the circuit; they do not give way, however, the instant a strong current begins to flow, since sufficient time must pass for the metal of which they are made to be heated to the melting point.

As it is desirable in most cases to provide a protective de-

vice that will act instantly, when the current rises suddenly to very great strength, magnetic cutouts are also provided. These are sometimes independent pieces of apparatus, and are called circuit breakers; and in some cases they form part of the motor starter. The latter is then called an automatic overload starter.

It sometimes happens that, when a motor is running, the current in the supply main $L\ L'$ for some reason dies out, and the machine comes to a standstill. In every such case, the starting box switch S should be opened; for, if not, when the current is re-established, the armature will be connected in the circuit with all the resistance of R cut out, and being at a standstill, the current passing through it will rise to a dangerous strength, as already explained. To prevent this contingency, starting boxes are made so that they will throw the switch S to the open position when the current dies out. Such boxes are called underload, or "no voltage" motor starters. Boxes are also provided with both kinds of safety devices—the overload and the underload.

Safety fuses are proportioned so that they will be melted with a current about 50 per cent stronger than the full-load current, provided this continues for a considerable length of time, say 5 minutes. The magnetic cutout is set so that it will not act with as weak a current as that, but when it is set for current of, say, double the normal strength, it will act instantly, if the current reaches this magnitude. Thus it will be seen that, if safety fuses and magnetic cutouts are both provided, the first are used to protect the armature from injury due to a prolonged current of about 50 per cent more than the full-load strength, while the latter are set to protect the machine from a sudden increase of much greater magnitude, or from a total suspension of the current.

Connections shown in Fig. 181 are the most desirable, but in many old-style motor starting boxes, and in some of modern make for small motors, the connections are made as in Fig. 182. The difference between the two is that in Fig. 181 the armature and the field coils are connected so as to form a closed circuit at all times, even when the switch S is in the open position, as shown.

In Fig. 182, when switch *S* is in the open position, the circuit between the field and armature is open. This is objectionable, because, if the field coil circuit is opened, there will be a heavy spark at the end of the contact *a,* and, in addition, there is danger of the insulation of the field coils being punctured. When wire is wound in coils of many turns, as is the case with the field coils of shunt motors, a very high voltage is developed at the instant the circuit is broken. This voltage is commonly called the kick of the coil. If a motor is of small capacity and for low voltage, say 1 horsepower and 110 volts, the kick may not be strong enough to damage the insulation, but it will produce a sufficient spark at the switch to roughen the contacts. With a larger motor of higher volt-

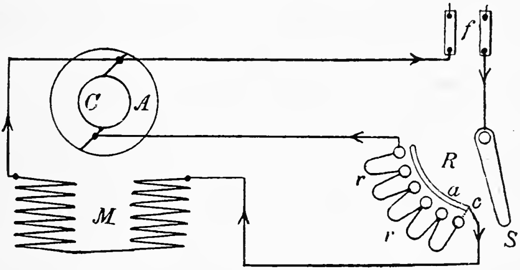

FIG. 182.

age, say 20 horsepower and 220 to 500 volts, the kick of the field coils will be so strong, if the circuit is opened, as to be almost sure to puncture the insulation. On this account motor starters should always be connected as in Fig. 181.

One objection to the connection of Fig. 181 is that when the motor is running, the field current has to pass through all the resistance loops *r r* of the starter. This objection, however, is far from being serious, because the resistance of these loops is small in comparison with that of the field coils, and it reduces the strength of the field current by an amount almost too small to be noticed. Some makers of starting boxes provide a plate contact, as shown at *a,* Fig. 182, for the purpose of letting the field current flow directly to the field coils without passing

through the resistance *r r*. To accomplish this result the plate is connected as shown dotted at *c* in Fig. 182. As will be seen, with these connections the field current flows through the arc *a* to the connection at *c*, Fig. 182, no matter where the switch *S* may be, between *c* and the other end.

Sometimes it is desired to connect a shunt motor so that it may be run in either direction. To accomplish this all that is necessary is to provide means whereby the armature current may be reversed; if the field current is also reversed, the motor will run in the same direction as before. To reverse a motor, a reversing switch must be used, as shown at *D* in Fig. 183.

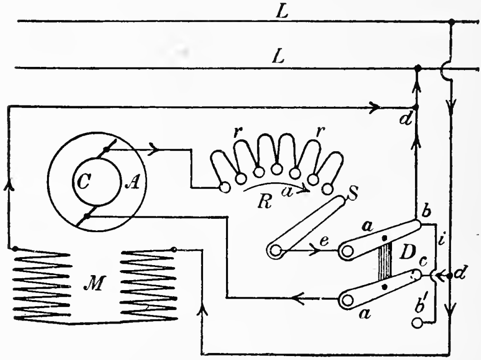

FIG. 183.

In this diagram, the main switch *B* and the fuses *f* of Fig. 181 are omitted for the sake of simplicity. The motor starter is placed at *R*. Most types of automatic overload and underload starters can be used with reversing motors, as they are not affected by the direction of the current through their magnet coils.

In Fig. 183 it will be seen that with the reversing switch *D* in the position shown, the current from the upper line wire passes to the lower commutator brush, and then through the armature and the motor starter, to contact *b*, and to the lower line. The field coil current is shunted from the points *d d*. With this arrangement, when the motor is stopped, by open-

ing the reversing switch or the starting box switch, the field coil circuit is not opened, as points *d d* are not disconnected, but the field coils are not disconnected from the line. It is difficult to make a reversing switch that will not open the field circuit, yet will break the line connection.

One way in which a reversing switch can be made to prevent this difficulty, of opening the field circuit, is shown in Fig. 184. In this diagram the field coil terminals run to the contacts *e, e′* and *f*, which are connected with contacts *b, b′* and *c* respectively, by the blades of the reversing switch *D*. The

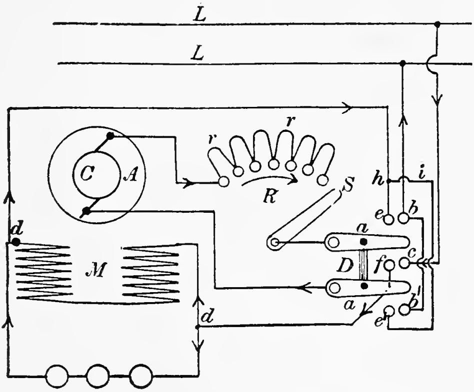

FIG. 184.

reversing switch is shown in the open position and, as will be noticed, the field coils are disconnected from the main line, but at the same time the field coil circuit is broken, so that the injurious effects produced by the kick of the coils will be experienced.

To get around this trouble, it is common practice to connect a number of incandescent lamps in parallel with the field coils, as indicated in the diagram by the three circles below the field. An objection to this plan is that, when the motor is running, some current flows through the lamps, and this causes just so much loss; but by increasing the number of lamps connected in series, the current can be cut down to a small amount.

There are ways in which the reversing switch can be made so that when the motor is running, the lamp circuit, shunted from points *d d,* will be open, and will only be closed just before the reversing switch *D* is opened. These constructions, are rather complicated and are hardly necessary, since the current that will pass through the lamp circuit around the field coils can be made so small as to amount to practically nothing.

CHAPTER XXXVII.

Changing the Speed of Motors.

MOTORS are manufactured so that they may run at a constant velocity or so that the speed may decrease as the load increases, or again so that the speed may be changed at will by means of a hand regulator.

That known as a series-wound motor is the simplest form. A motor of this type is illustrated diagrammatically in Fig. 185, in which *A* represents the armature, *C* the commutator and *M* the field magnet coils. The diagram also shows the way in which such a motor is connected with the circuit, *L L′* being the line wires, *B* a main switch for making or breaking the line connections, and *R* a rheostat which is used to start the motor. This type of machine is called a series motor, because the armature and the field coil windings are connected in series with each other, so that all the current that passes through the field coils also passes through the armature. As shown by the arrow heads in the diagram, the current first passes through the field coils and then through the armature.

This type of motor has a natural tendency to run fast when the load is light, and slow when the load is heavy. If the belt is thrown off, it will run away, and as it is loaded down, it will continually reduce its speed. If the load is increased without limit, and there is no circuit breaker or safety fuse to open the circuit, the motor will keep on reducing its speed until the current becomes so strong as to heat the wires sufficiently to burn the insulation, and thus destroy the machine. From this it will be seen that a series motor will not run at a constant speed unless the load is constant; with a varying load, the speed will vary.

There is no way in which a series motor can be made to run at a constant speed with a varying load; hence, if you have a machine of this kind and want it run at a constant velocity with variable load, make up your mind that it cannot be made to do it. Series motors are used principally to run trolley cars

and, to some extent, for operating hoisting machines, pumps and fans.

Although a series motor changes its speed with changes in the load, the rate at which it changes its speed may not always be just what is required. By means of what is commonly called a motor controller, the speed can be changed by hand in any manner desired, within certain limits. A motor controller is constructed in substantially the same way as a motor starter, that is, it consists of a resistance and a contact lever, the two being connected so that more or less of the resistance may be cut into the motor circuit by the movement of the lever. The difference between a motor starter and a controller is one of

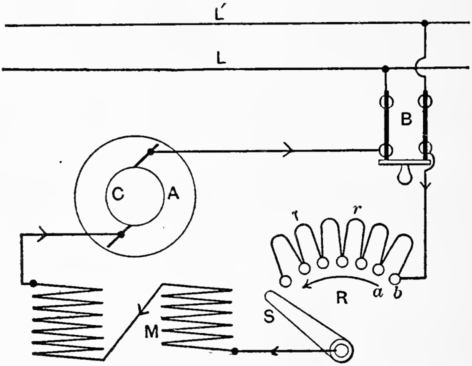

FIG. 185.

size only; the starter has to remain in circuit only a few seconds while starting the motor, and on that account the resistance can be made of small wire. The controller may have to remain in circuit for a long time; therefore, the resistance must be made of wire of such size that it can carry the full load current continuously without becoming overheated.

In Fig. 185, *R* may be taken to represent a motor starter or a motor controller, the loops *r r* representing the resistance that is cut in and out of the motor circuit. When the switch *S* is placed on the first contact to the left, the current entering at contact *b* will have to traverse all the resistance loops *r r;* but

when S is advanced to the contact b, the current can pass directly to the end of the field coils without passing through any of the resistance loops r r.

Motor controllers can be used as motor starters, but a motor starter cannot be used as a controller, simply because it is of too small capacity. If in Fig. 185, R is a controller, then it is evident that by the movement of the switch S by hand to any position, any number of the resistance loops r r can be cut

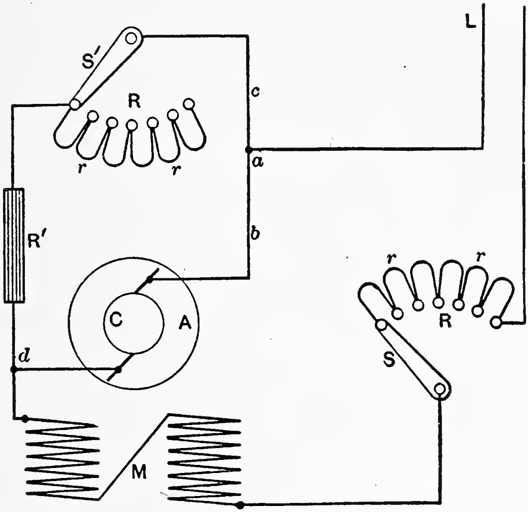

FIG. 186.

into or out of the motor circuit; hence, no matter whether the load be light or heavy, the speed of the motor can be varied by the movement of the controller switch S. The highest speed that the motor can attain will be with the switch S resting upon contact b, and the lowest will be with the switch resting on the first contact at the left-hand side. Thus the speed regulation is limited to a certain range, which is made large or small by increasing or decreasing the resistance of the controller R.

Another way in which the speed of a series motor can be

varied at will is by providing a circuit around the armature, which might be called a bypass circuit. Such an arrangement is illustrated in Fig. 186. In this diagram it can be seen that when the current reaches point *a* it can split, part going through the motor by way of wire *b*, and part around the armature by wire *c*. In the bypass circuit there is a resistance R', and a speed controlling resistance R. The first-named resistance is made of such value that, when the controller switch S' is in the position shown and all of the resistance R is out of the circuit, the current flowing through the bypass is not more than the field coils M can carry, in addition to that coming from the armature. With this position of the switch, the current diverted from the armature is the greatest, and the speed the lowest. By moving the switch S' to the right, additional resistance is cut into the bypass and thus more current is forced through the armature, and the speed is increased, for the same load.

This means of controlling the speed of series motors by hand has the objection that all the energy used up in the bypass represents so much loss. It is much like varying the speed of an engine by opening a connection between the live steam pipe and the exhaust.

By connecting the field coils in parallel, as illustrated in Fig. 187 the natural speed of a series motor can be increased. Another way to increase the speed is by using a bypass circuit around the field coils, as shown in Fig. 188. This arrangement has the objection of wasting current the same as that shown in Fig. 186; but it is much more economical because the loss in the bypass is only a small fraction of the total energy used by the motor. The loss in the arrangement of Fig. 186 is probably ten times as great as in that of Fig. 188. The advantage of Fig. 188 over Fig. 187 is that, by making the resistance R in the bypass circuit in adjustable form,—that is, like a controller—the increase in speed of the motor can be made greater or less, as may be desired; while by the coupling of the field coils, in parallel only one change in speed can be obtained. Just how much the speed will be increased by the arrangement of Fig. 187 cannot be determined accurately without knowing all

the dimensions of the motor, but it will be somewhere between 20 and 100 per cent higher.

Ordinarily, stationary motors are of the shunt-wound type, and such machines run naturally at practically constant velocity without regard to the size of the load. When a motor of this type is running with a full load, if the belt is thrown off, it will not increase its speed more than 3 or 4 per cent. Motors of this type are called shunt-wound because the current that passes through the field coils does not pass through the armature, but is shunted from the latter.

These motors run at a constant speed without regard to the

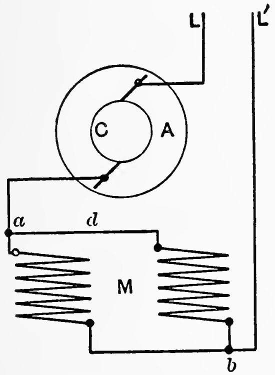

FIG. 187.

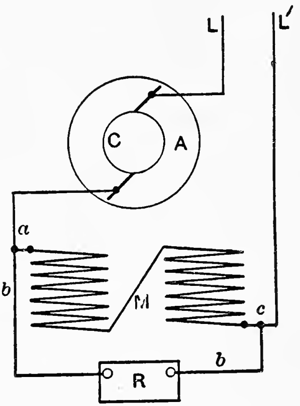

FIG. 188.

load they carry because the current that passes through the field coils remains constant no matter how much that through the armature may vary. Owing to the constant strength of current in the field coils, the strength of the magnetic field in which the armature revolves remains constant. The speed at which a motor armature will revolve in a constant magnetic field is dependent upon the voltage of the current. This voltage is counteracted by the back pressure developed by the motor armature and also by the voltage required to overcome the armature resistance. In shunt-wound motors, the armature re-

sistance is so low that the voltage required to overcome it is only 2 or 3 per cent of the total; so that the back pressure of the armature, or counterelectromotive force has to attain nearly the same magnitude whatever the load on the motor may be.

Since the constant current through the field develops a constant magnetic strength, and since in a magnetic field of constant strength the armature back pressure is constant at a given speed, it follows that the only variation there can be in the speed of the armature of a shunt-wound motor is that due to the slight difference in the amount of voltage balanced by the

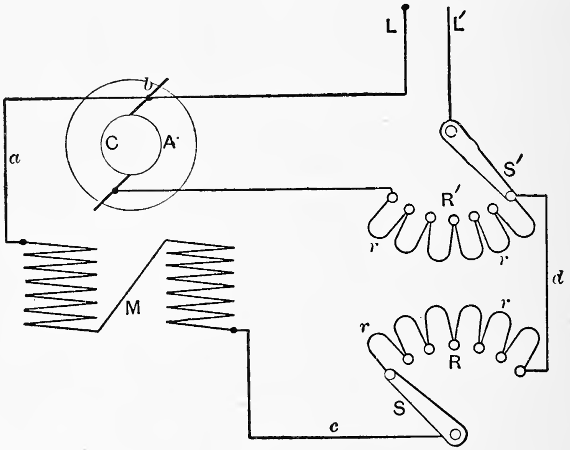

FIG. 189.

armature resistance with weak and strong currents; and this varies from nearly nothing, at light load, to 2 or 3 per cent of the total line voltage at full load.

From the foregoing explanation it will be seen that there are two ways in which the speed of shunt-wound motors may be varied, one by changing the strength of the current flowing through the field coils, and the other by placing in the armature circuit a resistance that will absorb some of the line voltage, thus leaving less for the armature back pressure to balance. By means of the last named expedient the speed of the motor

can be reduced, since the armature will have to develop a lower back pressure. By means of the first-named method the speed of the motor will be increased, because, if resistance is introduced in the field circuit, and the current is thereby reduced, the magnetic force will be reduced, and as a result the armature will have to revolve faster to develop the required back pressure.

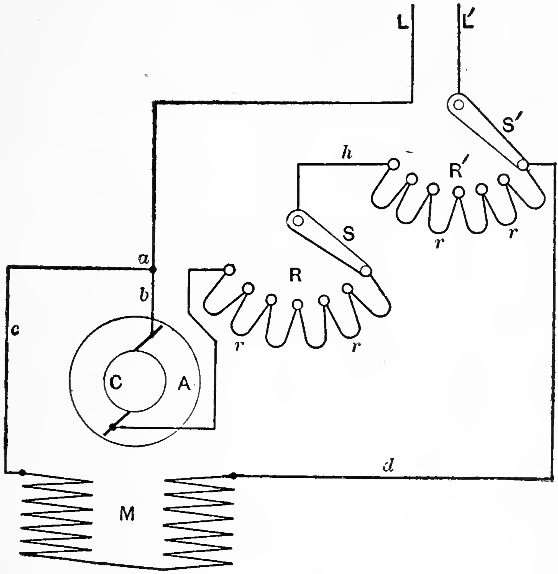

FIG. 190.

Fig. 189 illustrates the way in which a shunt-wound motor is connected so as to increase its speed by inserting resistance in the field circuit. The resistance in the field circuit is shown at *R*, and by making it in the form of a controller—so that more or less of it may be put in service—the increase in speed can be graduated. This arrangement can also be used to make the motor variable in speed and controllable by hand, but the variation in velocity will be from the normal speed to higher speed.

The resistance *R* may be made of small wire because it has to carry only the field current, which is generally a small fraction of the armature current, from 1½ per cent in large motors to 5 or 6 per cent in small ones. The resistance of *R*, however, will have to be large to make any great change in the speed. The ordinary field regulators used with generators can be used for this purpose, a regulator for a one-hundred light machine being about the proper size for a 10-horsepower motor of the same voltage. If one regulator does not give all the change in speed desired, use two connected in series.

Fig. 190 shows the way in which a shunt-wound motor is connected for varying the speed by inserting resistance in the armature circuit. By this means the motor can be made to run slower than the normal velocity, and it can be used as a variable speed motor controlled by hand regulation. In this diagram *R* is the ordinary motor starter, and *R′* is the resistance cut into the armature circuit. This resistance *R′* may be an ordinary motor controller, such as is used with series-wound motors of the same size and voltage. If it is desired with this arrangement simply to reduce the speed of the motor, the switch *S′* is turned until the proper velocity is obtained. If it is desired to vary the speed, the switch *S′* is moved as often as a change in speed is desired. The starter *R* cannot be used in place of the controller *R′* simply because it is not of sufficient capacity to carry the current continuously.

CHAPTER XXXVIII.

Motor Starters and Controllers.

IN CHAPTER XXXIV the general principles upon which motor starters are constructed were fully explained. In this chapter, and in others to follow it, it is proposed to illustrate and explain a number of the most commonly used motor starters and speed controllers.

Motor starters are used for the purpose of starting a motor, only. Motor controllers are intended to regulate the speed at which the motor runs after it is in operation. Both devices are made so as to be used in connection with motors intended to run in one direction or in both directions. The construction of a motor starter is such that it controls the speed at which the motor runs in the act of starting. The construction of motor controllers is such that they can control the speed of the motor all the time. Thus it will be seen that both devices really act in the same manner, and, with the exception of a few differences in the details of construction, they are substantially the same. Controllers, however, are more massive in construction, and are able to carry large currents for long periods of time.

It is undesirable to use a motor starter that will perform only the function of starting a motor. If a motor is running and the current in the line fails for any reason, the machine will come to a stop; then if the current comes on again, it will catch the motor with the armature connected in the circuit without any resistance. As a result there will be sent through it a current strong enough to burn it out in a few seconds. Because of this fact it is necessary to provide a protective device that will open the motor circuit, if the current fails for any reason. Motor starters with this safety feature added to them are called "no-voltage" starters.

When a motor is running, if the load upon it is increased, the current will also increase, so as to give the machine the additional power required to carry the extra load. If the load is increased sufficiently, the current passing through the armature

will be strong enough to burn it out. It is desirable, therefore, to have a protective device that will disconnect the motor before the current can become so strong as to injure the armature. Motor starters are made with such a device, and when they have this in connection with the no-voltage attachment, they are called "no-voltage and overload" starters. A type of no-voltage starters is shown in Fig. 191. It is manufactured by the Cutler-Hammer Manufacturing Co., Milwaukee, Wis. The course of

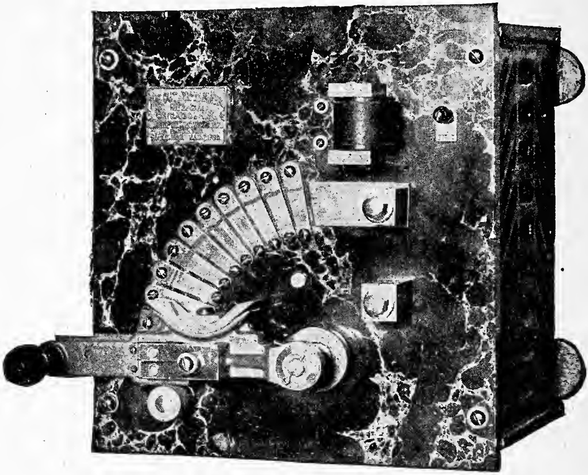

FIG. 191.

the current in passing through such a starter is shown in Fig. 192.

In this diagram the lines *P N* represent the line wires, and *M* is a double-pole main switch by means of which the motor circuit may be disconnected from the main line. At *f, f* safety fuses are provided which melt and open the circuit if the current becomes too strong.

It will be seen that the wire *a* connects the left side of the switch *M* with the lower brush of the motor, and also, through the wire *g′*, with one end of the field coils. Wire *b* runs from the right side of *M* to the binding post *G* at the bottom of the motor

starter. This is connected with the stud *D*, around which the switch arm *A* swings. If *A* is moved to the right, as soon as it makes contact with the first of the contacts *E*, the main current passes through the resistance in the starter, which is indicated

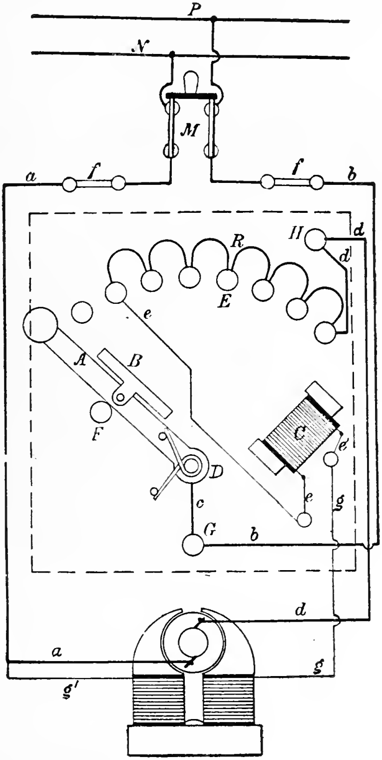

FIG. 192.

by the loops *R*, and reaches wire *d*, through which it passes to the upper brush of the motor; thence through the motor armature to wire *a*, and through the latter back to the main line. Current for the field coils of the motor branches off from the

first E contact at the left, through wire e to a magnet coil C; thence to wire g, and through the motor field coils to wire g', which connects to the wire a.

Current passing through the magnet C energizes it so that when the switch arm A is moved as far as it will go to the right, and the piece B rests against the poles of C, the attraction of the latter will hold A, the piece B being made of iron. As is shown in the diagram, there is a spring around the stud D, which spring acts to swing A around to the stop position; but, as long as a current passes through C, the attraction of the latter is more than the spring can overcome. If the current from the line fails, magnet C becomes de-energized, and the spring is free to swing A around to the stop position. If the line current is then re-established, the motor is not caught connected in the circuit without resistance in series with the armature. A stop is provided at F, so as to prevent the spring around D from swinging A too far.

In the second diagram, Fig. 193, the connections within the motor starter are substantially the same as in Fig. 192, and the releasing magnet C is actuated in the same manner. An additional connection is made between wire e and the iron core of magnet C, through wire e'', so that when B rests against the poles of C the current may pass through the coil of the latter directly from A without having to go to the right-hand contact E and thence through the resistances R to wire e. The effect of this arrangement is to slightly increase the strength of the magnet, and to provide an additional path for the current, so that if, for any reason, the circuit through the resistances R should be broken, there would still be another path through e'' and the core of C. There is a spring around the stud I which acts to swing the switch lever A around to the open position whenever the current through the motor fails, precisely the same as in Fig. 192, but it is not shown in the diagram.

Fig. 193 is the type made by the Cutler-Hammer Co. for motors, using currents not exceeding 50 amperes. For larger motors, this company provides the starter, which is diagrammatically shown in Fig. 194. In this design, the circuit connections are the same as in the two preceding diagrams, Figs. 192 and 193, with the exception that when the lever A is raised to

the vertical position and all the starting resistance R is cut out of the armature circuit, a spring connecting piece D is forced into contact with the blocks E E, thus providing another, and

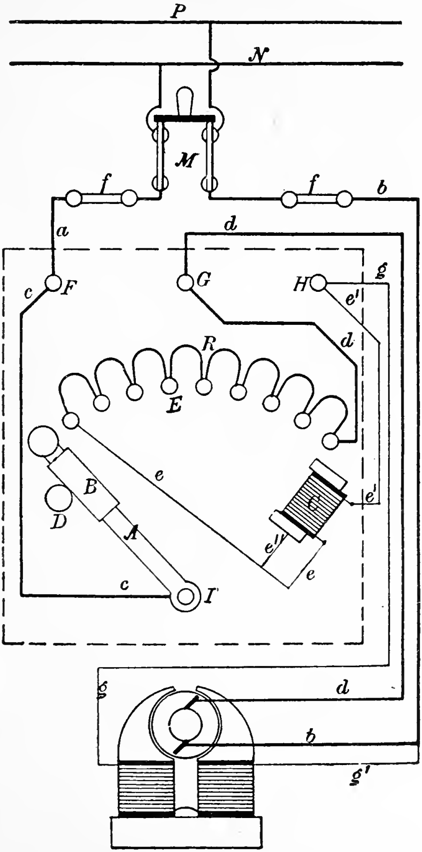

FIG. 193.

more direct, path for the main current between wires a and d. The iron block B on lever A, is located at the extreme end, and

magnet C is placed outside of the resistance contacts $I\,I$, thus enabling a comparatively small magnet to force the connector D against $E\,E$ with sufficient pressure to make a good contact.

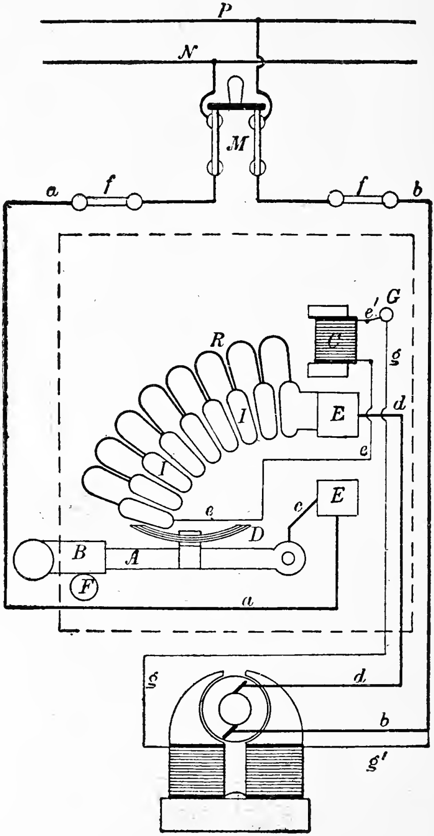

FIG. 194.

One advantage of this construction is that the contacts $I\,I$ need not be as large as when the blocks $E\,E$ are not used, and, in addition, if, for any reason, the connections in the resistance R

become broken or imperfect, the current can find a path through *E E* and the connector *D*.

In these three diagrams it will be noticed that the connections between the motor and the starter are such that the circuit through the field coils of the motor is never opened. As was fully explained in Chapter XXXVI, this arrangement is necessary to prevent serious sparking at the last contact to the left of the starter, when the motor is stopped, and also to avoid injuring the insulation of the motor field coils. In Fig. 192, if the circuit is traced from the upper motor armature brush it will be found that it passes through wire *d* to the right-hand contact *E*; thence through the resistances *R* to wire *e,* through magnet *C* to wire *g,* through the motor field coils to wire *g′*, through wire *a* to the lower motor brush, and finally through the armature to the upper brush, which is the starting point. Thus it will be seen that the motor field and armature are connected so as to form a loop, or closed circuit. In Fig. 193, if we start from the upper motor brush through wire *d,* we come back through wire *g* to the motor field through wires *g′* and *b,* to the lower brush, and through the motor armature to the starting point. This is also the connection of the armature and field shown in Fig. 194.

Plain motor starters that are not provided with an automatic releasing magnet *C* are sometimes connected after the manner shown in Fig. 195, but this is not an arrangement to be recommended. In looking at this diagram it will be seen that, if the main switch *B* is closed, the circuit through the field coil *D* of the motor will be closed. If now the switch lever *C* of the motor starter is moved to the right, over the contacts *E,* the circuit through the armature *A* of the motor will be closed, and the motor will be set in motion.

If when the motor is running we open the main switch *B,* the motor will be disconnected from the main line *P N,* and the circuit through the motor field will not be opened. As the line current is cut off, the motor will come to a stop, and then we can move switch lever *C* to the open position without doing any harm. If we should undertake to stop the motor by opening switch lever *C* instead of *B,* the result would be a considerable sparking at the contacts *E,* and if we then opened switch *B* to

disconnect the motor from the main line, the circuit through the field *D* of the motor would be opened, and if the machine were large, the probabilities are that the insulation would be damaged.

The objection to arranging the circuits of the motor and starter in the manner shown in this diagram is that while with it the motor can be stopped without injury, there is danger of the switch levers not being manipulated in the proper order,

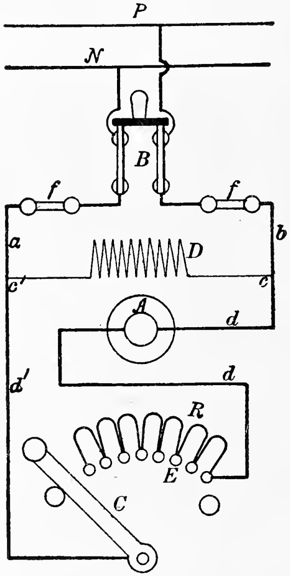

FIG. 195.

either through ignorance or carelessness. Furthermore, if the switch *B* is opened first, as it should be, there is danger of forgetting to open *C* when the motor comes to a stop. And in such an event there would be great liability that the switch *B* might be closed to start up the motor, without first returning *C* to the open position.

CHAPTER XXXIX.

No-Voltage and Overload Motor Starters.

IN THE LAST chapter we described automatic no-voltage motor starters, which are also called underload automatic starters. Figs. 196 and 197 are now given to illustrate no-voltage and overload starters, the first being made by the Cutler-

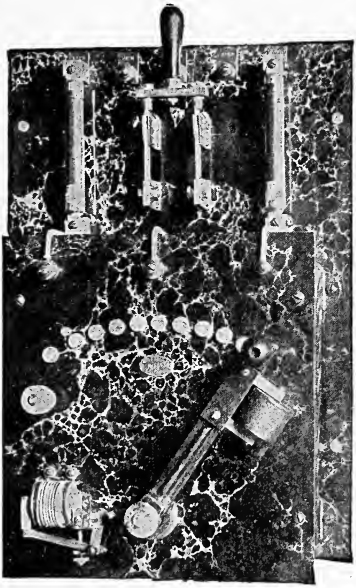

FIG. 196.

Hammer Co., and the second by the Ward Leonard Electric Co. Fig. 196 shows an arrangement which combines with the motor starter proper, a two-pole main switch, and two safety fuses. Fig. 197 might be arranged in the same way.

For Fig. 196 the circuit connections are shown in the dia-

gram, Fig. 198. As will be seen, the main switch *M* has its upper left-side terminal connected with the *N* line through wire *e e′* and the lower right-side terminal with the *P* line through wires *g g′*, the safety fuses being located at *f f*. From the lower left-hand terminal of *M*, wire *a* runs to binding post *G* and the upper right-hand terminal of *M* is connected through wire *b* with the lower brush of the motor armature. From *G* through wire *h* the circuit runs to magnet *D* through the coil of which the entire current that actuates the motor is passed. From *D*

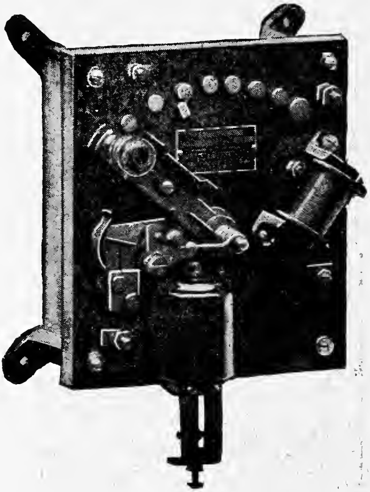

FIG. 197.

through wire *c* the circuit runs to switch *A*, and when this is moved over the contacts *E* the circuit continues through wires *d*, *d′* and *d″* to the top motor brush, thence through the motor armature to wire *b* and back to the main line.

From the left-hand *E* contact a wire *i* is run to magnet *C* and then through wires *j*, *j′* and *k* to the motor field coil, from which the circuit continues through *k′* to wire *b*. It will be seen that magnet *C* is connected in the same way as is the same magnet in the no-voltage starter, and it acts in the same manner; that is, it holds lever *A* in the extreme right-hand position

against the tension of a spring wound around the stud upon

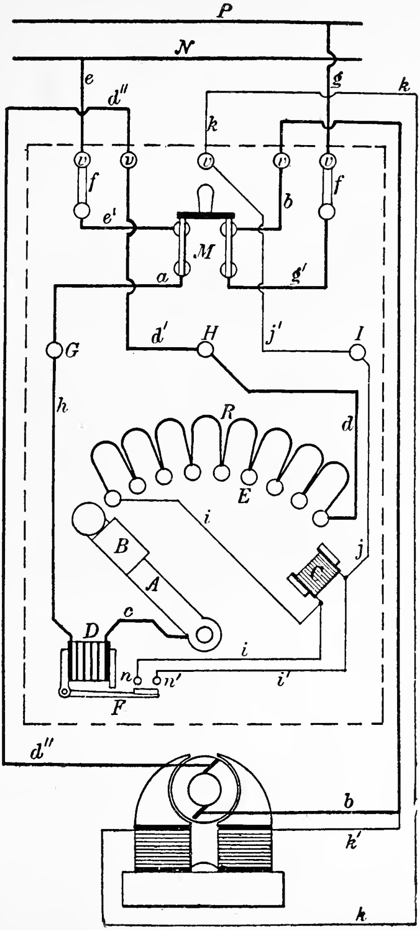

FIG. 198.

which *A* swings. The magnet *D* is traversed by the whole cur-

rent, hence its strength increases as the whole current increases, and when the latter reaches the strength for which the magnet is adjusted, the armature *F* is lifted and its end connects the terminals *n n'*. In this way the magnet *C* is short-circuited and loses its strength, permitting the spring to swing *A* around to the open position, and stop the motor. From this description it will be seen that magnet *C* acts precisely the same as in the no-voltage starter, and that the office of magnet *D* is to shut off the current from *C* whenever the current passing through the motor is strong enough to lift the armature *F*.

Automatic motor starters, whether of the type shown in the last chapter or like those here presented, hold the lever *A* firmly in the extreme right-hand position when the motor is running and the latter cannot be stopped by moving *A* back to the stop position, unless a considerable force is employed. To stop motors provided with such starters, the main switch *M* is opened and then, as soon as the current through the motor dies out, the magnet *C* loses its strength and allows the force of the spring around the stud of *A* to swing the latter to the open position. With the overload starters, it is possible to stop by simply lifting the armature *F* so as to short-circuit magnet *C*.

As it is a very easy matter to lift *F*, much easier than to open the main switch *M*, some men get in the way of resorting to this method of stopping the motor; but it is not advisable to follow the practice, because, when this is done, the circuit connection between lever *A* and the contacts *E* is broken while the full current is passing, and as a result there is considerable sparking at the contacts *E*, which in time gets them so rough as to prevent the switch from working freely.

Fig. 199 shows the circuit connections for the starter illustrated in Fig. 197, all parts of which, except the overload magnet *G*, act in the same manner as in Fig. 198. The action of the overload magnet, however, is quite different. The lever *D* is held in position by the catch *F* and a spring around stud *I* acts to swing *D* upward. The end of *D* rests upon a contact with which wire *c* is connected, so that, with the parts in the position shown in the diagram, the current from *A* passes through *D* to wire *c* and thus to line wire *N*. The magnet *G* is of the solenoid type and exerts a force to lift the plunger *s*. When the

main current becomes strong enough, magnet *G* lifts plunger *s* and the latter, striking a blow against the end of *F*, throws the catch at its upper end out of engagement with the lever *D*, when

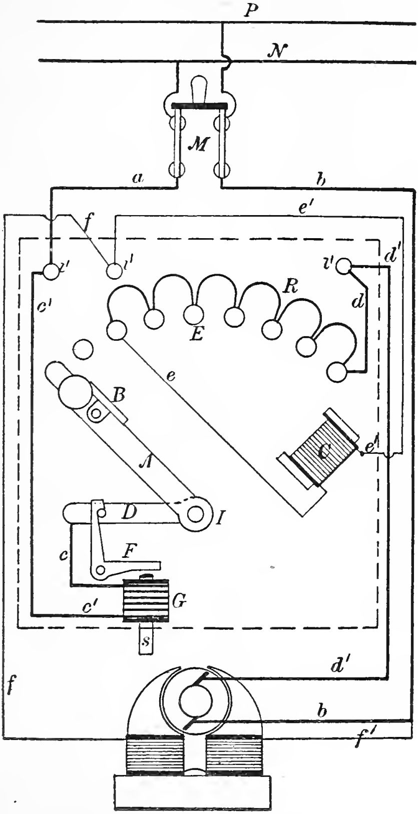

FIG. 199.

this lever, actuated by the spring around stud *I*, flies upward and breaks the contact between wire *c* and switch *A*, thus opening the circuit through the motor armature.

As will be noticed in Fig. 197, the plunger *s* is guided by a frame attached to the lower side of magnet *G*. This plunger is held in its normal position by means of a set screw which is seen projecting below the frame, and by adjusting this screw, the device can be set so as to cause the plunger *s* to lift with different strengths of current. There is a scale marked in amperes on the front of the frame that guides *s*, and attached to the latter there is a pointer that moves over this scale, so that, by the movement of the adjusting screw, the magnet can be set to act at any desired number of amperes. With this starter, the motor can be stopped by lifting *F* so as to release *D*, but, as stated in connection with Fig. 198, the practice is a bad one, and should not be followed.

It will be noticed that in Fig. 198 fuses are shown at *f f*, while in Fig. 199 there are none. It may be asked why they are used in one case and not in the other; and, since the overload magnet acts to open the circuit when the current becomes too strong, why are fuses used at all? In answer to these questions it may be said that this type of starter can be used without fuses, if desired, as the overload magnet is generally sufficient protection. Fuses can be used with Fig. 199 just as well as with Fig. 198.

All things considered, it is advisable to use the fuses, because they act in a manner somewhat different from that of the overload magnet, and hence afford additional protection. The overload magnet will respond to a very sudden increase in current, even if it lasts for only a short time, and on that account gives complete protection for the motor against sudden rushes of current. The safety fuse will not respond to a sudden increase in current because it requires some time to heat the fuse wire up to the melting point, but sufficient increase in current, if continued, will melt the fuse.

Fig. 200 shows a type of motor starter made by the Cutler-Hammer Co. for use in connection with very large motors, 100 horsepower or more. The complete apparatus is shown as filling one whole panel of a switchboard, the diagram of wiring connections for which is shown in Fig. 201. At the top of the panel is located a circuit breaker which acts in the same manner as the overload magnet in the starters already explained. The

magnet of this circuit breaker is shown at *F*, and is arranged so

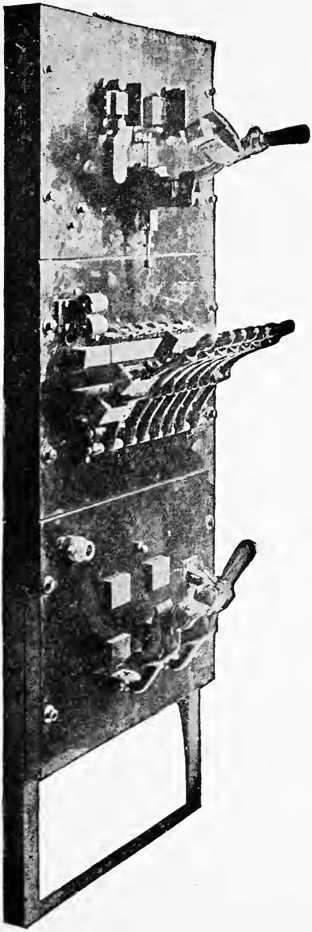

FIG. 200.

as not to be traversed by the whole of the main current, as this

would require very large wire. The current for this magnet is shunted from the ends of the bent bar *I*, which is so made as to offer proper resistance to force the required current through the magnet. The lever of the circuit breaker connects the contacts *L L*, and the circles *gg* represent magnets used to extinguish the spark produced when the contact across *L L* is broken. The switch at the lower end of the panel is the main-line switch, which, in the closed position connects the contacts *S S* and *S′ S′*, the pairs on the right and left sides, respectively, being connected with each other.

Along the center of the panel is a row of switches for the purpose of cutting out the resistance in the armature circuit; that is, they take the place of switch lever *A* in the other starters. These switches are made to interlock each other so that No. 2 cannot be moved until No. 1 is closed, and so on for all the others. The small magnet *n* is for the purpose of holding these switches in position and of releasing them all when the main switch is opened. At *G* a pilot lamp is placed to indicate whether there is a current in the circuit before the switch is closed, and also for the purpose of lighting up the panel when desired. At *H* is placed a switch to close the lamp circuit when the main switch is open. This switch is opened before the main switch is closed. When the main switch is open, the contacts *p* and *q* are connected with the *S′* and *S* contacts directly above them.

When the main switch *M* is closed, the current from main-line wire *P* in wire *b* passes through *g′* and the blow-out magnets *g* to wire *h* and to contact plate *C*, thence by wire *h′* to magnet *n* and to wire *i*, through lamp *G* to *i′* and contact *p* of main motor-starter switch. If switch *H* is closed, the current will pass to *q* and thence to the lower contact *S* above it, to wire *a* which runs to the opposite side *N* of the main line. If the circuit breaker *F* is now closed, the main current will flow through *I* to contacts *L L*, to wire *c* and to the upper *S′* contact of the main switch. If this switch is also closed, the current from the upper *S′* will pass to the lower *S′* and thus through the motor armature to wire *e′* and to contact plate *D*.

If the first or left-hand switch of the center row is now closed, the main current will pass from *D* through the starting resistances *R* to contact plate *C*, through the switch lever

to contact *B*, thence through wire *d* to the upper contact *S*,

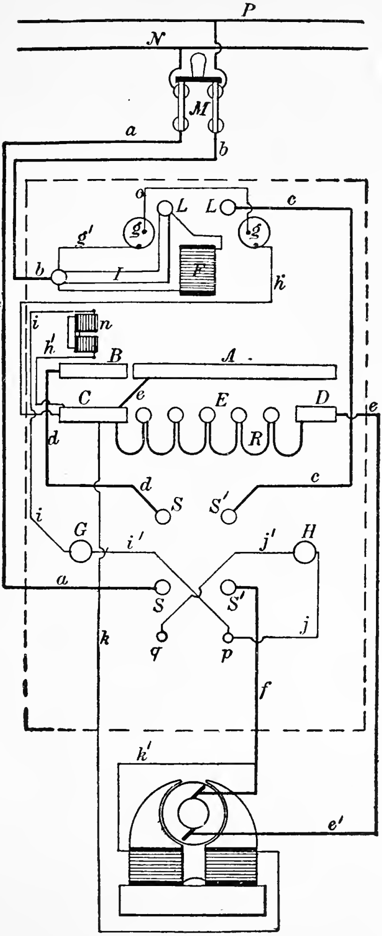

FIG. 201.

through the main switch lever to the lower *S* and to wire *a* thus

returning to the main line. The field current will branch from wire *f* through wire *k′*, and from the field will go to contact plate *C* through wire *k*. The plate *A* is connected with *C* by wire *e* so that, as the switch levers are successively pressed into position, the contacts *E* are connected with *A*, one after the other, thus cutting out in succession the several sections *R* of the starting resistance. As switch *H* is open when the motor is running, the current through magnet *n* will break as soon as the main switch breaks the connection between the contacts *S S* and *S′ S′*.

CHAPTER XL.

Motor Controllers.

FIG. 202 shows a controller that is arranged to vary the speed of the motor by cutting resistance into the armature circuit and also into the field circuit. By cutting resistance into the armature circuit the speed is reduced, and by cutting it into the field circuit the speed is increased. Fig. 203 shows a

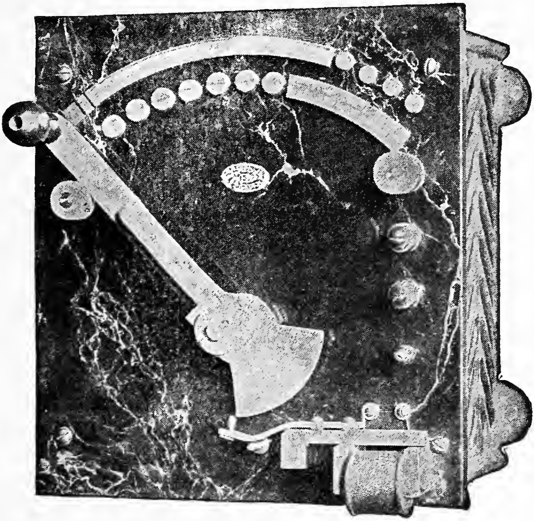

FIG. 202.

controller that is arranged to vary the speed of the motor in the same way as Fig. 202, and in addition is provided with means for stopping the motor quickly. This quick-stopping addition is very desirable in connection with motors used to operate printing presses and also for many kinds of motor-driven machine tools. Both illustrations are of controllers made by the Cutler-Hammer Manufacturing Co.

Circuit connections for Fig. 202 are shown in the diagram, Fig. 204. The connections are substantially the same as for a motor starter, the wire *a* running from one side of the main switch *M* to one of the motor brushes, and the other side of the switch being connected with the switch lever *A* through wires *b* and *c*. The resistances represented by the loops *R*, which connect with the segment *G*, are in the circuit of the armature of the motor, and the resistances represented by the small loops

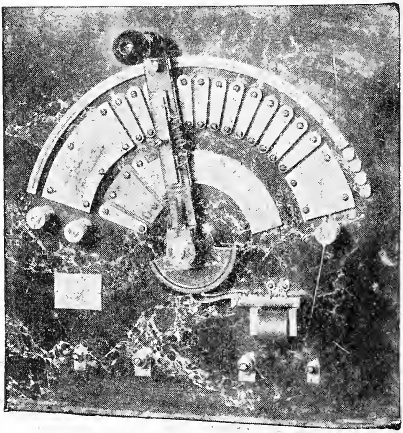

FIG. 203.

r, which are connected with the segment *E*, are connected in the motor field circuit.

Magnet *C* acts the same as in the motor starters, to open the circuit through the motor armature whenever the current dies out in the main circuit. The segment *B* which is attached to the lower end of lever *A* is provided with teeth, as indicated at the upper portion, these teeth covering the whole segment. The armature *D* of magnet *C* carries a spring catch at the outer end, which engages with the teeth on the segment *B*, when *D* is drawn down into the position shown in the diagram, by the attraction of *C*.

The resistances R are made of sufficient size to carry the whole current that passes through the motor armature for any length of time without getting too hot. On this account, if it is desired to run the motor at a low velocity, the lever A is moved over the contacts connected with the resistances R until

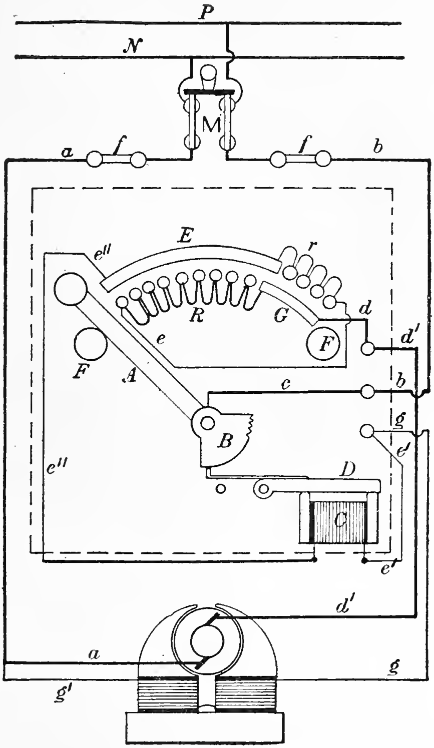

FIG. 204.

the proper speed is obtained, and is left in that position. The catch on the end of D engages with segment B in this position and prevents A from being thrown back to the stop position by

the force of the spring that is placed around the stud upon which the lever swings. This spring is not shown in the diagram, but is mounted in the same way as on the motor starters.

If it is desired to run the motor at its normal velocity, the lever *A* is moved around until it comes in contact with segment *G* and thus cuts out all the resistance in the circuit of the motor armature. If a still higher velocity is required, the lever is carried further ahead, so as to pass off the segment *E* and rest on one of the small contacts connected with the resistances *r*. In this way resistance is cut into the field circuit of the motor, and, owing to the reduced strength of the field, the speed of rotation of the armature is increased.

When lever *A* is moved to the extreme right-hand position, the motor will run at the highest velocity, and when *A* is on the first contact at the left, the speed will be the lowest. In either one of these two positions, or in any intermediate position, lever *A* is firmly held by the catch attached to *D* so long as current passes through the motor. If, however, the line current is interrupted from any cause, the magnet *C* loses its strength, *D* can no longer hold the catch against *B*, lever *A* swings back to the stop position, and there is no danger of injuring the motor armature if the line current is re-established.

For the controller shown in Fig. 203 the wiring connections are given in the diagram, Fig. 205. This controller, as already stated, is the same as Fig. 202, with the addition of means for stopping the motor quickly, which is effected by converting the motor into a generator, so that the momentum of the armature is absorbed in developing a current; in other words, the power given out by the armature as a generator acts as a brake to arrest the motion.

For this controller the operation is as follows: If the lever *A*, Fig. 205, is moved to the right from the position in which it is shown, so as to cover segment *F*, the main current which comes from wire *c* to *F* will pass through *A* to the contact *E*, upon which *A* may be resting; then through the resistances *r* to segment *G* and thus through wires *h* and *h′* to the motor armature, and from the latter through wires *b′* and *b* to the opposite side of the main line. If lever *A* rests on the first *E* contact at the left, the motor speed will be the lowest, while if it

rests at the extreme right side of *G*, the speed will be the highest, precisely as in the case of Fig. 204.

When *A* is in the position shown, the circuit through the

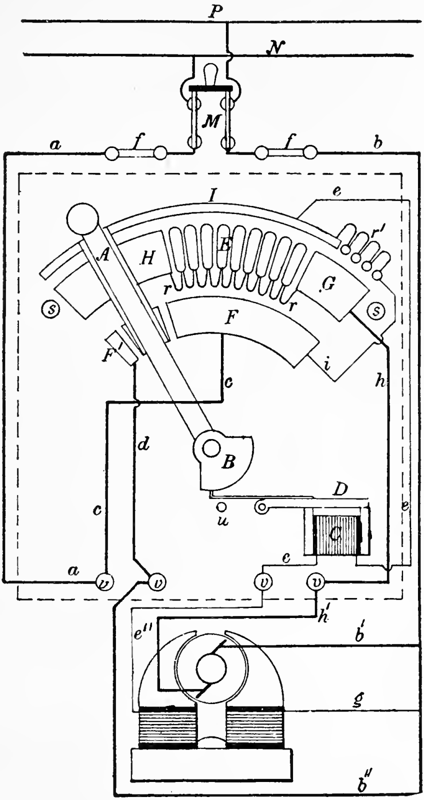

FIG. 205.

armature of the motor is broken, as the current from *F* cannot pass in any way to *G*. If *A* is moved to the left so as to cover contact *F'*, then this contact will be connected through the segment

H and the resistances *r* with segment *G*, and thus the circuit of the motor armature will be closed and any current generated in the latter will be forced through the resistances *r*. It will be noticed that when lever *A* is in the left-hand position, resting on *F′*, the circuit through the field of the motor is closed, as segment *F* is connected by wire *i* with the right-hand contact of the row connected with the resistances *r′*, so that the line current can pass to wire *c* and thus through magnet *C* to wire *c″*, and through the motor field to wire *g* and the opposite side of the main line.

If the contacts of the controller are arranged precisely as shown in Fig. 205, the current generated in the motor armature when *A* is moved to the left position will be such as the magnitude of the total resistance *r* will permit it to be. Under these conditions the motor may stop more quickly than desired, or not quickly enough. If the stop is not quick enough, the segment *H* may be made shorter and a separate contact provided to the left of it, this contact to be connected with any point of the resistance *r* which may be found necessary to effect a stop in the proper time. Or, if the stop with all the resistance *r* in the circuit is too rapid, an additional resistance can be cut into the circuit. The contacts and the resistances can be arranged so as to adjust the rapidity of the stop to suit any particular case.

Small circles *s s* are stops to prevent swinging lever *A* too far in either direction. Whenever it is desired to make a slow stop, lever *A* is returned to the position in which it is shown, but if a quick stop is desired, it is carried around to the left until it strikes the stop *s*. The spring that swings the lever back to the stop position is mounted upon the central stud around which the lever swings.

Whenever the motor is stopped for any length of time, the main switch *M* is opened so as to break the circuit through the field coils. The fuses *f f* protect the motor against a strong current, and magnet *C* protects it against sudden stoppage of current in the main line, so that the machine is as well guarded as if connected with an overload and no-voltage motor starter.

CHAPTER XLI.

Reversing Motor Controllers.

IN MANY cases it is desired to be able to run a motor in either direction, and for that purpose a reversing controller is required. Fig. 206 is a controller which is arranged to run the motor at full speed in either direction, but, if provided with resistance of sufficient capacity, may be used to obtain

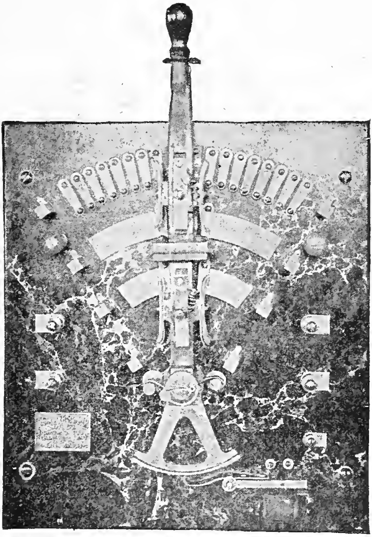

FIG. 206.

different speeds by cutting resistance into the armature circuit. Fig. 207 shows another form of reversing controller, made by the same firm, the Cutler-Hammer Mfg. Co., with which a number of different speeds may be obtained in one direction, and two speeds when running in the opposite direction. Controllers of this type are used in cases where it is desired to run at

several speeds in the forward direction, which is the direction in which the motor is run most of the time, and at only one or two speeds when the motor is reversed.

Circuit connections for Fig. 206 are shown in Fig. 208. The current from main line *P* passes through wires *b* and *b'* to the upper binding post *v'*, and thence through wires *d'* and *d* to the left-hand contact *E'*. Through wire *g* the current reaches the motor field and thence passes through wires *e''* and *e'* to magnet *D*, through wire *e* to wire *c''*, to contact *u*, to wire *c'*, through *u'* to wire *c* and to wire *a*, which connects with the main line *N*.

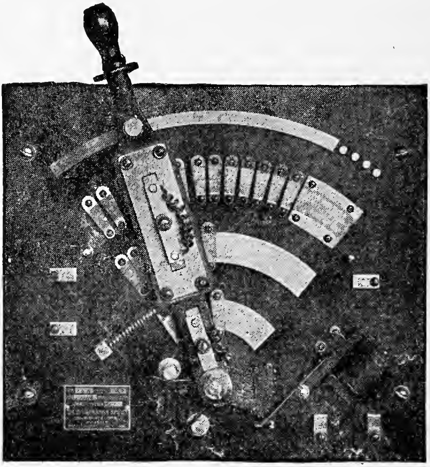

FIG. 207.

The magnet *D* acts to hold lever *A* in any position in which it may be placed, precisely the same as the magnet *C* in the controllers explained in the last chapter. The lever *A* is divided into two parts, *A* and *B*, by an insulating section marked *t*.

If the main switch *M* is closed and the lever *A* is in the vertical position, the circuit through the motor field will be closed, as will be seen by following wire *g*; but the armature circuit will not be closed, as there is no connection between the contacts *E E'* and *F F'*. The contacts *E E'* are connected with each other by

the wires $i\ i$, and contacts $F\ F'$ are connected with $G\ G'$ by means of the wires $h\ h'$.

If lever A is moved to the right, the section above t will

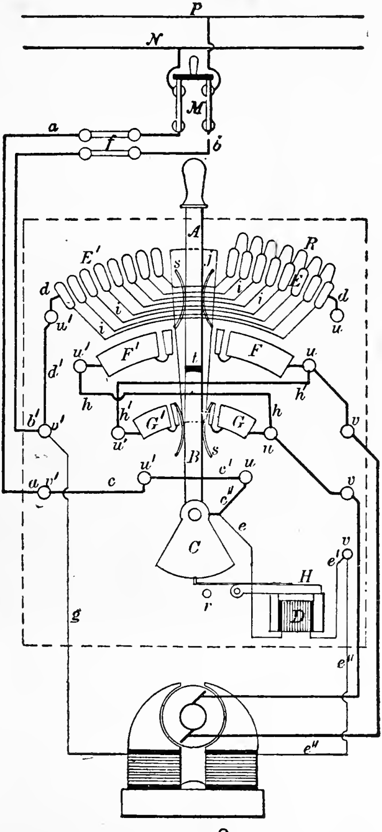

FIG. 208.

connect F with the contacts E, and then the current from the E' contact at the left will pass through wire i to the E contact at the extreme right and through the resistance loops R until it

reaches lever A. Through this lever the current will pass to F, to the small contact u, to binding post v and to the lower motor brush. Returning from the upper motor brush, the current will reach G and, through the lower section B of the lever A, will reach the stud around which the lever swings and with which wire c'' is connected. From this point through wires c' and c the lower binding post v' is reached, and thus wire a, which is connected with the N side of the main line.

In this case it will be observed that the current reaches the motor armature through the lower brush. Now, if the operating lever is moved to the left, it will be found, by tracing the circuit through the contacts E and E', the connecting wires i and resistance loops R, that the current from the extreme left-hand E' contact will reach lever A wherever it may be resting on the E' contacts, will pass to F', and thence through wire h will reach the upper motor brush, and will return from the lower brush through wire h' to contact G', and thence through section B of lever A to wire c'' and back to the N side of the main line through wires c', c and a.

Thus it will be seen that if, when the operating lever is moved toward the right, the armature rotates clockwise, when the lever is moved to the left, the armature will rotate counterclockwise; for in the first case the current will enter the armature through the lower brush, while in the second it will enter through the upper brush.

The piece j is not connected with the circuit, and is simply provided to form an even path for the lever to move over. The small contacts marked u and u', four placed in a row on each side of the main contacts, are for the purpose of making a more perfect connection when the operating lever is in the extreme side position. The spring connectors marked $s\ s$ press against these contacts when in the side position. The actual form of these connectors, and of the u and u' contacts, is well shown in Fig. 206.

As in the two controllers described in the last chapter, the segment C is provided with teeth on its periphery, and the spring catch attached to the armature H of magnet D engages with these teeth to hold the operating lever in any position. As in

this type of switch the lever swings in both directions, springs are placed around the stud that act to bring it to the central position when moved either one way or the other. The arrangement of these springs can be seen in Fig. 206.

For the controller shown in Fig. 207 the circuit connections are given in the diagram, Fig. 209. This controller, as already explained, is arranged so as to give several speeds in one direction, but only two in the other direction. The motor shown in this diagram is of the compound type, the shunt field coils being marked *S S* and the series coils *m m*. The magnet *D* acts in the same way as in Fig. 208. The shunt field current branches from wire *b* through wire *g*, and passes from the field coils to wire *e″*, up to the binding post *v*, to wire *e′*, thence through magnet *D* to wire *e* and segment *L*. The main current passes through wire *b* to the series field coils *m m*, through wire *b′* to binding post *v′* and thence to contact *I*. The lower motor brush is connected through wires *d′* and *d* with contact *G′*, and the upper brush is connected through wires *h′* and *h* with contact *G*. The *N* side of the main line is connected with the stud around which the operating lever swings, through wires *a* and *c*.

If the lever is moved to the right far enough to cover the first *E* contact, the current from *I* will pass through all the *r* resistance to *A*, thence to *F*, through wire *i′* to *G′*, to wires *d* and *d′*, and to the lower side of the motor armature. From the upper armature brush the current will return through wires *h′* and *h* to *G*, and through section *B* of the operating lever to wire *c*, to wire *a*, and to the opposite side *N* of the main line.

As the position of *A* is advanced toward the right, section after section of the resistance *r* is cut out and the motor speed is correspondingly increased. When *A* reaches contact *I* the normal motor speed is obtained, and if it is advanced still farther along *I*, the sections of the resistance *r′* are cut into the circuit of the shunt field coils *S S* and the speed of the motor is further increased. Thus it will be seen that as many changes in velocity may be obtained as there are *E* contacts, plus the contacts connected with the *r′* resistance in the field circuit.

If the operating lever is moved to the left, the motor is reversed, as the *F′* contact is connected with *G*, so that the current from contact *I*, after passing through all the *r* resistances to one

of the wires *n* and the corresponding *E′* contact, will, through *A*, reach *F′*. Then, through wire *i*, the current will pass to *G*,

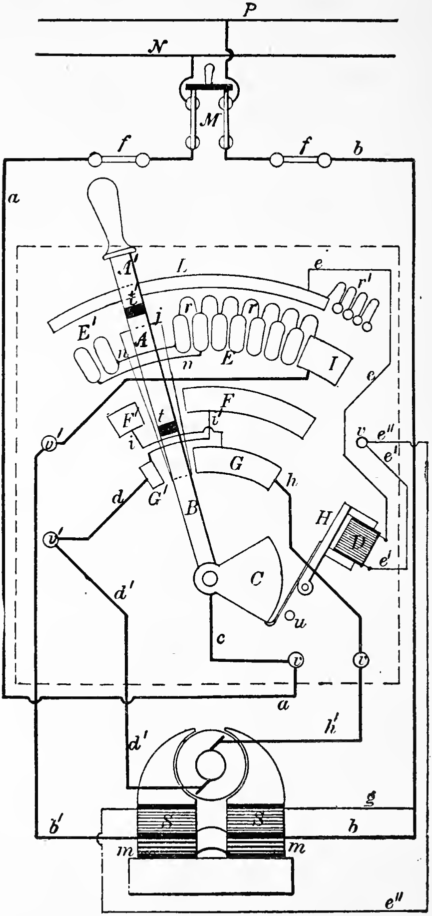

FIG. 209.

and through wires *h* and *h′* to the upper motor armature brush, which is the reverse of the direction when the operating lever

is moved to the right. If the lever is moved far enough to cover the first E' contact, all the r resistances will be left in the circuit of the motor armature, but if it is moved to the second E' contact, one section of this resistance will be cut out. As may be readily seen, the second E' contact may be connected with other E contacts, so as to cut out two or more sections of the r resistance, and thus give a greater difference between the two speeds obtained in the reverse motion. The upper end A' of the operating lever is connected with the lower section B, so as to keep the shunt field circuit closed when the lever is moved to the stop position—*i. e.*, the position in which it is drawn.

CHAPTER XLII.

Motor Controllers for Printing Presses.

IN MANY cases it is desired to have the controller so arranged that the motor may be stopped quickly from several different positions. For such service it is evident that the simple arrangements heretofore shown cannot be used, because,

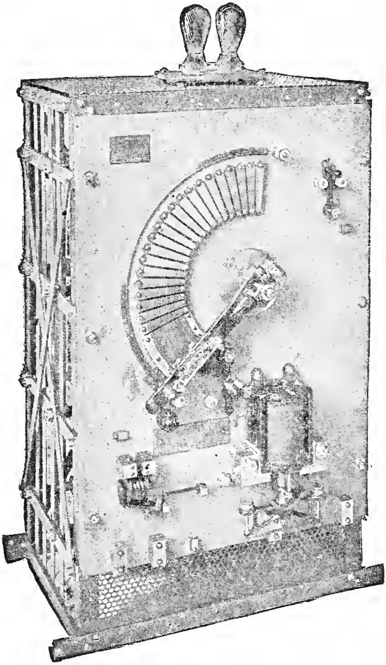

FIG. 210.

with them, the motor can be controlled from only one position, and that is the place where the controller is located. In the operation of a printing press, the work being done has to be

observed from several different positions, and the observers at any of these points should be able to stop the machine instantly if anything goes wrong.

The controller shown in Fig. 210, made by the Cutler-Hammer Co. for printing press service, is arranged so that, while the motor is started by the movement of the controller lever, it can be stopped by simply pressing a push button located at any desired point, and there may be any number of these buttons located wherever they may be required. To accomplish this result, the main switch of the controller is arranged so as to be actuated by a magnet. When a current is passed through the coil of this magnet, the switch is closed and the motor is properly connected with the main circuit.

When the current through this magnet is interrupted, the main switch is opened and thus the motor circuit is broken. The circuit through the coil of the switch-operating magnet is extended so as to include all the push buttons by means of which the motor is to be stopped. These buttons are connected so as to keep the circuit normally closed, but when any one of them is depressed the circuit through the switch magnet is opened, and the switch then opens the motor circuit.

In Fig. 210 the magnetic main switch is seen at the lower end of the panel, a little to the right of the center line. The small magnetic switch to the left of this is an overload device, to open the circuit in case the current becomes too strong. The two incandescent lamps on top of the controller are used to reduce the strength of the current that passes through the magnet of the main switch after the latter has been lifted into the closed position. The magnet of this switch is of the solenoid type, and in these magnets the current required to lift the plunger when it is in its lowest position is much greater than that necessary to hold the plunger up after it has been raised to its highest position. By cutting the two lamps into the magnet circuit, after the switch has been closed, the current strength is greatly reduced; thus energy is saved and, in addition, the magnet coil is prevented from becoming overheated.

Fig. 211 shows the general arrangement of this controller. The magnet of the main switch is shown at *B;* when current passes through this magnet, the plunger *j* is raised and the con-

nector attached to its lower end joins the contacts *v v*, thus closing the circuit through the motor. When the current through *B*

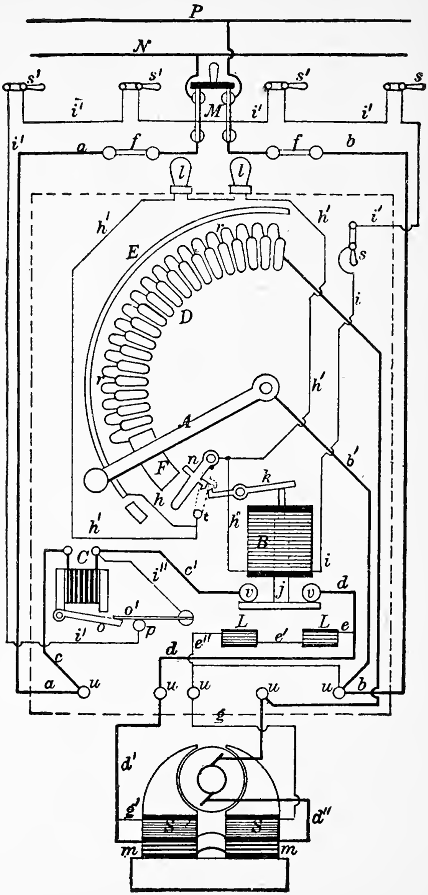

FIG. 211.

is shut off, the plunger *j* drops, thus opening the circuit through the motor armature. The small switch *n* is in the position indi-

cated in dotted lines, when the circuit through *B* is open, and rests upon the contact *t*. The catch *k* holds *n* in this position and a spring acts to pull it into the position in which it is shown.

In the circuit *i′* the switches *s′ s′* represent the push buttons that are located at the several points from which it is desired to stop the motor. If all these *s′* switches are closed, the closing of switch *s*, located on the controller panel, as shown in Figs. 210 and 211, will close the circuit through *B*, and thus connect *v v* and establish the circuit through the motor. The upward movement of *j* will cause its upper end to strike *k* and release switch *n*, thus breaking the connection with *t*. When *n* rests on *t*, the wire *h* is in direct connection with *h″* through switch *n*, but when *n* is released and swings to the position in which it is drawn, the wire *h* is disconnected from *h″*, and the current in the latter must pass through the two lamps *l l* to reach wires *h′* and *h*. From this it will be seen that until the upper end of *j* strikes *k* the lamps *l l* are short circuited by the switch *n*, but as soon as this switch is released and swings away from *t* the lamps are cut into the circuit, and thus the current passing through *B* is greatly reduced, but not until *j* has been raised so as to connect the two contacts *v v*.

Whether *j* is down or up, the circuit through *B* is closed, providing all the switches *s′* and *s* are closed, for, as will be seen, if we follow wire *b* to lever *A*, we shall reach segment *E*, with which wire *h* is connected, and if *n* rests on *t*, the current will pass to *h″* and through *B* to wire *i*, through switch *s* to wire *i′* and to contact *p*. From this contact, through spring *o′*, the current will pass to wire *i″*, thence through magnet *C* to wire *c*, and finally to wire *a*, which is connected with the opposite side of the main circuit.

When the main controller lever *A* is in the stop position, it presses switch *n* over onto contact *t*, thus cutting out the two lamps *l l*. If *A* is not in the stop position, switch *n* will not be pressed over onto *t*, and if such is the case, the current passing through *B* will not be strong enough to lift the plunger *j*. The result of this is that, if the current in the line should fail while the motor is running, and lever *A* is resting on one of the contacts *D*, the circuit will be opened through the motor on account of the current through *B* dying out, and as *B* cannot lift *j* with

the two lamps *l l* in circuit, the motor circuit cannot be closed again until *A* has been returned to the stop position and has forced *n* over the contact *t*. In this way the motor is protected from the danger of being started with all or a large portion of the armature resistance *r* cut out of the circuit.

Magnet *C* is for the purpose of protecting the motor against an excessive current due to an overload. When the main current, all of which passes through *C*, becomes strong enough, the

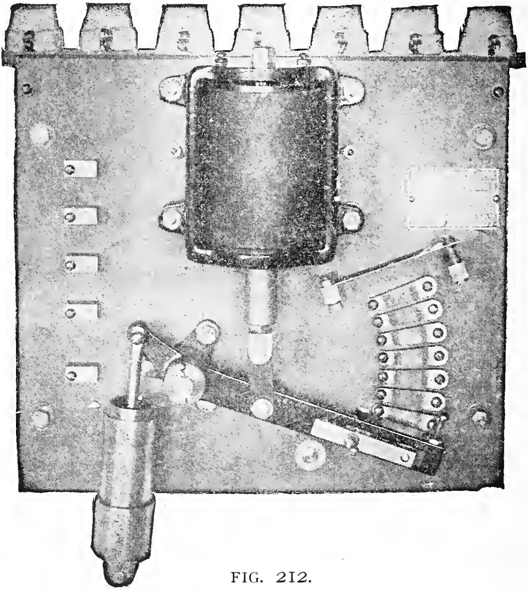

FIG. 212.

armature *o* is lifted and thus breaks the connection between *p* and the spring *o′*. As will be seen, this break opens the circuit *i′*, in which the magnet *B* is included, and causes the main switch to be opened by the dropping of plunger *j*. The two coils *L L* are magnetic blowouts and are provided to blow out the sparks formed between the contacts *v v* and the connector carried by *j*, when the switch is opened.

Fig. 212 shows a form of magnetic controller used to operate

motors that are stopped and started automatically, or are actuated from a distant point, or in which it is desired to simplify the operation of starting. The diagram, Fig. 213, shows the way in

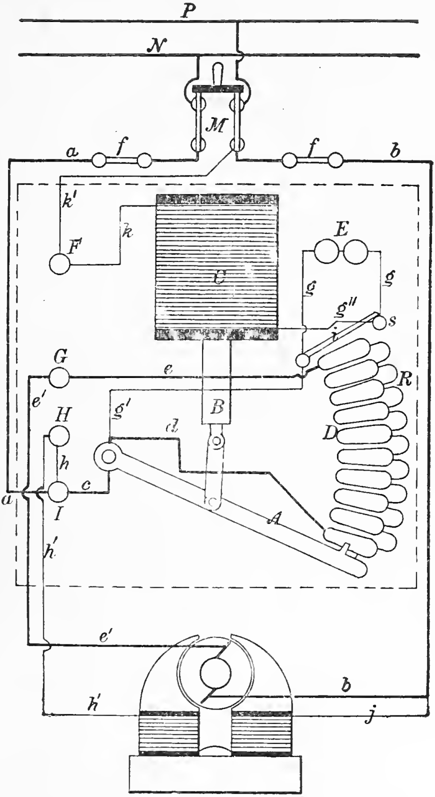

FIG. 213.

which the starter is connected when used for the purpose of simplifying the operation of starting. With this arrangement all the attendant has to do is to close the main switch M and the starter does the rest. As soon as M is closed, the circuit through

the motor is closed; through wires k' and k the current passes to magnet C, through wire g'' and switch i to the wire g', and thus to wires c and a and the opposite side of the main line.

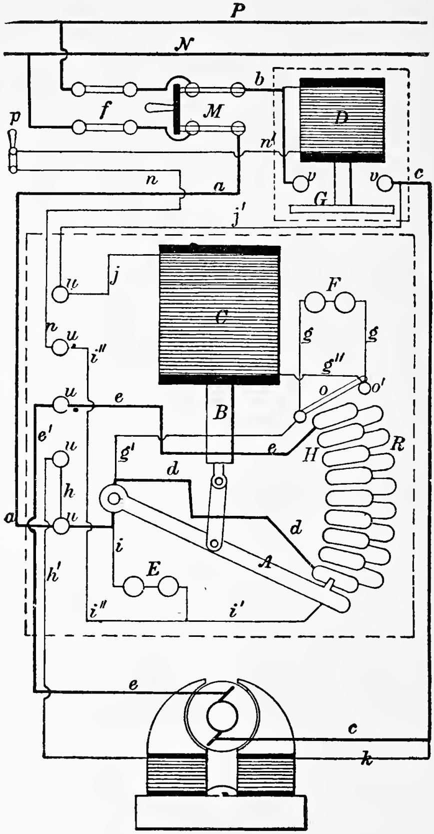

FIG. 214.

As soon as magnet C is energized, it draws up the plunger B and thus swings lever A over the contacts D and cuts out the

resistance in the circuit of the motor armature. The dashpot shown in Fig. 212 opposes the pull of magnet *C* and thus regulates the speed at which *A* is moved over the contacts. When *A* reaches the top position, it strikes the small switch *i* and opens the circuit with contact *s*, thus cutting in the two lamps indicated at *E*, or any other suitable resistance, so as to reduce the current passing through *C*.

Fig. 214 shows how this controller is arranged to be actuated from a distance. In this case a magnetic main switch *D* is provided, the circuit through which is opened and closed by a small switch *p* located at any point desired. When *p* is closed, the current passes through *D* to wire n', and to wire *n*, to wire i'', and thence to wire i', which connects with a contact upon which lever *A* rests. Through *A* the current passes to wire *a* and to the opposite side of the main line.

As soon as the current passes through *D*, it lifts its plunger, and thus the connector *G* joins the contacts *v v* and closes the circuit through the motor. The operation of magnet *C* will now be the same as in Fig. 213. As soon as *A* moves upward, it passes off the contact with which wire i' is connected, and then the current passing through *D* has to flow through the resistances at *E* to reach the opposite side of the line, and in this way the current through the main magnet *D* is cut down immediately after the connector *G* has been raised into position. As in Fig. 213, when *A* reaches the top position it opens the switch *o* so as to cut the resistance *F* into the circuit of *C*.

This type of motor starter is used to operate automatically pumps that deliver water into a tank, where it is desired that the motor be stopped when the water reaches a certain level in the tank, or when the pressure reaches a certain point. In the first case, the switch *p* is actuated by a float in the tank, and in the second case it is actuated by a pressure regulator.

CHAPTER XLIII.

Motor Starters with Electromagnetic Switches.

MOTOR starters of large size are made not only in the forms shown in previous chapters, but also with separate switches that are magnetically operated for making the various changes in the circuit connections. Starters and controllers of this type are more elaborate and expensive than the designs in which the various circuit combinations are effected by the movement of a single switch lever that swings over a row of contacts, but to offset this increased cost, the separate switch construction gives greater wearing capacity and offers less liability to developing short circuits.

In a starter such as is shown in Fig. 211, it can be easily seen that, if the current handled amounts to several hundred amperes, there is danger of seriously damaging the contacts D if the lever A fails to make a good connection with them as it swings upward; and in descending the sparking will be quite severe unless there are a large number of contacts, so as to divide the resistance r into so many sections that the voltage required to drive the current through each one is very small.

When a switch of this type is new, if it is properly constructed, there is no difficulty in obtaining perfect contact for all positions of the lever A, but the wear upon the rubbing surfaces will not be uniform and, as a result, in the course of time some of the D contacts will be lower than the others. This unevenness will cause the sparking to increase when the lever A swings downward, and the increase in sparking will result in more rapid wear, thus producing still greater irregularity in the surface. Unless this inequality in wear is remedied by truing up the surface of the contacts, a time will come when the sparking at some point will be great enough to burn them out.

Owing to these facts, the independent switches which are capable of withstanding harder usage are considered by many to be preferable, notwithstanding their greater cost. There are many designs of independent switch motor controllers and starters, some being comparatively simple and others very elab-

orate. One of several designs made by the Cutler-Hammer Co. is shown in Fig. 215, and the diagram of the circuit connections is given in Fig. 216. The switch in the lower left-hand corner is the main switch which opens and closes the motor circuit. The switch in the upper left-hand corner controls the circuits through the four magnets of the four remaining switches.

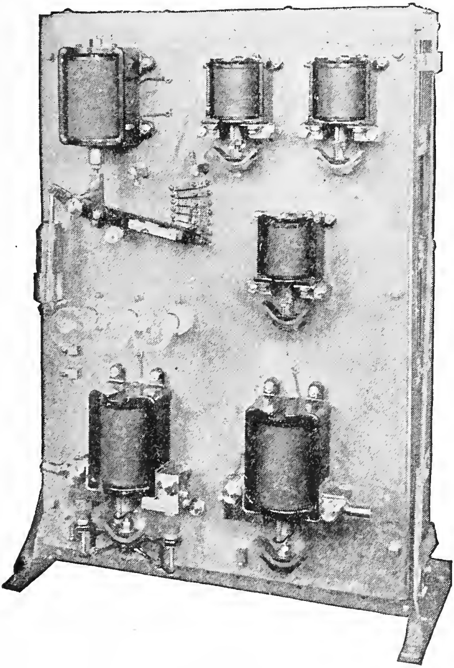

FIG. 215.

Each one of these switches, when actuated by its magnet, cuts out a portion of the starting resistance in the armature circuit.

As will be noticed, the starting resistance is cut out in four sections, while with switches of the types shown in previous chapters it is cut out in three or four times this number of sections. It is generally considered that the greater the number of

sections into which the resistance is divided, the smoother will be the acceleration of the speed of the motor in starting. This

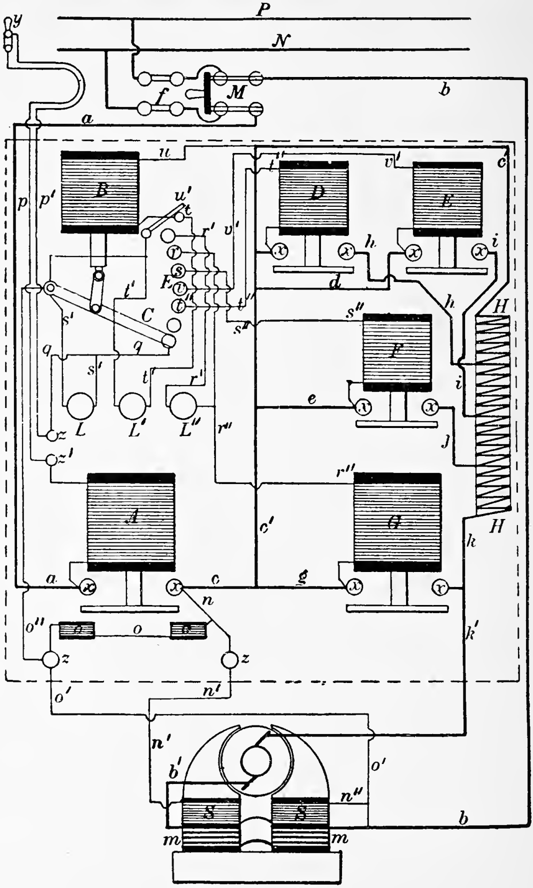

FIG. 216.

conclusion is true theoretically, but in practice it is found that the difference in the smoothness of the acceleration when the

number of sections into which the resistance is divided is four or five, or double or triple this number, is so slight as not to be noticeable. The fact is that no violent change in the speed of the motor can be effected unless nearly all the starting resistance is cut out at once, because the inertia of the armature and other moving parts resists any sudden change.

In starters such as that shown in Fig. 211 the number of *D* contacts is made large, not for the purpose of securing smooth acceleration of velocity, but to reduce the sparking.

In a starter such as is shown in Fig. 215, the only switch at which there is any tendency to spark heavily is the main starting switch, in the lower left-hand corner. When the motor is stopped, this switch opens the main circuit and, if the load on the motor at the time is large, the sparking may be severe. To reduce this sparking to the lowest point, magnetic blowouts are provided. The general operation of the starter can be well understood from the following explanation of the diagram, Fig. 216:

When the main switch *M* is closed, the circuit from the *N* side of the main line passes through wire *a* to magnet *A* of the starting switch. From magnet *A* the circuit extends to binding post z' and thence through wire *p* to the small switch *y*. By means of this switch *y*, which may be located at any desired point, the operation of the starter is controlled; for, as can be seen, if *y* is open, the circuit is broken, while if it is closed, the circuit continues through wire p' to post *z*, then through wire *q* to lever *C* of the *B* switch, to wire o'', to wire o', and thence to the opposite side of the main line through wire *b*.

This circuit being established by the closing of switch *y*, the magnet *A* of the starting switch will draw up its plunger and thus connect the contacts *x x*. Then the main circuit through the motor will be from wire *b* through the series field coils *m m* of the motor, through the motor armature to wire k', through the starting resistance *H H* to wire c' and wire *c*, and thence through the connector of switch *A* to wire *a* and the opposite side of the main line.

At the instant this circuit is closed by the closing of the starting switch *A*, a current will pass through wire *u* to magnet *B*, out through contact *t* to the small switch u', thence to the stud

around which *C* swings, and through wires o'' and o' to wire *b* and the main line *P*. Magnet *B* will now begin to draw up its plunger and thus swing lever *C* over the contacts *E*, the speed of the movement being regulated to any desired point by adjustment of the dashpot seen in Fig. 215.

Circles *L*, L' and L'' represent incandescent lamps arranged so as to be cut into the circuits of the magnets *A*, *B* and *G* after these have raised their plungers to the top position. The circuits through the other three switch magnets are opened after they have performed their parts in the operation of starting the motor. When *C* is in the position shown, the circuit of magnet *A* from binding post *z* is through wire *q* to *C* and thence to o'', but when *C* is moved to the second *E* contact, wire *q* is disconnected, and the circuit is then made through wires s' s' and lamp *L*, thus cutting resistance into this circuit and reducing the strength of the current that passes through *A*. For every other position of *C* above this, the circuit of *A* is through wires s' s' and lamp *L*.

When *C* moves up as far as contact t'', the circuit through magnet *D* will be closed through wire t''. The plunger of this switch will then be raised, closing the circuit between wires *h* and c' and thereby cutting out the top section of the starting resistance *H H*. When *C* advances to contact *v*, the circuit through magnet *E* will be closed through wire v', and the plunger of this switch will be raised, connecting the wires *i* and *d* and cutting out the upper two sections of the starting resistance. When *C* passes onto *v* it opens the circuit through *D* and the plunger of this magnet drops, but this does not matter at this stage, as switch *E* now closes the circuit between wires *i* and *d*.

When *C* reaches the contact *s*, the circuit of magnet *F* is closed through wire s'', and the lifting of the plunger of this magnet closes the circuit between wires *e* and *j*, thus cutting out the upper three sections of the resistance *H H*. When *C* passes onto *s*, the circuits of magnets *D* and *E* are both opened. When *C* reaches contact *r*, the circuit through magnet *G* is closed through wire r'', and at the same time the circuit of magnet *F* is opened. Closing the circuit of *G* lifts the plunger and connects wires *g* and *k*, thus cutting out the whole of the starting resistance *H H*.

When this position is reached, the three magnets, *D*, *E* and *F*, are cut out of the circuit, as they are no longer required,

since magnet *G* makes the proper circuit connection. When *C* reaches the top contact, the lamp *L″* is cut into the circuit of magnet *G* through the wire *r′*, and lamp *L′* is cut into the circuit of magnet *B*, by a projection on *C* which actuates the small switch *u′*, thus breaking the connection with contact *t* and forcing the current to pass through wires *t′ t′* and lamp *L′*.

From the foregoing, it will be seen that the magnetic switches *D, E* and *F* are rendered active only during the short interval of time when they are used to cut out their respective sections of the starting resistance *H H*, and that immediately after they have performed their work the current through their magnets is cut off. When the motor is running at full speed, the magnets *A, B* and *G* are energized, but one of the lamps *L* is cut into each circuit, so that the current passing through the magnets is small, just strong enough to hold the plungers in the upper position.

When the operating switch *y* is opened, the circuit through the magnet *A* of the starting switch is opened and the plunger drops, thus opening the main circuit through the motor. As soon as this circuit is opened the circuits through the magnets *B* and *G* are opened. As switch *A* opens the main motor circuit, there may be considerable sparking between the connector and the contacts *x x*, if the motor is carrying a heavy load at the time, but this spark is broken by the action of the blowout magnets *o o* which are provided for that purpose. In any case, the sparking cannot be injurious, because the motor is so connected permanently in series with the armature that the circuit through the shunt field coils *S S* is never opened. That such is the case can be readily seen by tracing the motor circuit from the upper armature brush. This circuit runs through wire *k′* to resistance *H H* and into wire *c′*, which connects with wire *c*, the latter connecting with wire *n* to binding post *z* and from here through wire *n′* to the left field coil *S* and out to wire *n″*, thence through the series coils *m m* to wire *b′* and the lower motor armature brush and through the armature to the starting point. This is the connection with all the switches either opened or closed; hence, unless the current passing through the motor is very strong when the machine is stopped, the sparking at the contacts of switch *A* will be small.

CHAPTER XLIV.

Testing Electric Motors.

TO BE able to make a test of a motor in any place and under any conditions, it is necessary to understand the principles upon which the test depends. These principles are simple and easily understood, and it is proposed to explain the subject fully in what follows.

In making a test of a motor, we can find out a number of things. We can ascertain the amount of electrical energy it absorbs, and also the amount of work it delivers at the pulley. By deducting the last amount from the first, we can find what amount of energy is lost in transforming the electrical energy supplied to the motor into the mechanical energy it delivers at the pulley, and if we divide the latter energy by the electrical energy, we shall obtain the commercial efficiency of the machine. We can not only find out the proportion of the electric energy that is lost in the motor, but we can go further and ascertain how it is lost, what proportion is lost in the armature, what proportion in the field, and what proportion in other ways. We can, in addition to determining the amounts of energy absorbed and delivered, find the difference in efficiency of the motor for different percentages of load.

Motors can be tested in two ways—by purely electrical methods, or by a combination of mechanical and electrical methods. In this chapter we will explain the purely electrical methods.

Electrical tests can be made in a simple manner and in a few minutes' time, but such are only accurate enough to give a fair idea of what the machine is doing. The simplest test of all for direct-current motors is made with a single ammeter, to determine the efficiency of the motor and also the power it is developing. For this test the ammeter is connected in the motor circuit, so as to measure the total current passing through the machine. The way in which the instrument is connected is fully explained in Chapter XXIII, Part I.

Having connected the ammeter, the belt is thrown off and the motor started up running light. When the starter has been

turned to the last point, and the armature is running at full speed, the ammeter is read, and the number of amperes indicated is noted. The motor is now stopped, the belt is put on, the machine started and full load applied. We now read the instrument for the second time.

Suppose that the first reading is 10 amperes, and the second is 100 amperes, then we know that to run the machine light 10 amperes are required, and that to drive the full load the current must be increased by 90 amperes. From this we might conclude that the electric current available to do work was 90 amperes, and that lost in the motor was 10, but this conclusion is not strictly correct. The truth is that, when the machine is driving the full load, the loss in it is greater than when it is running light. For the present, we can assume that when full load is on, it requires 12 amperes—that is, an increase of 2 per cent over the no-load loss—to overcome the loss within the machine, and the current available for doing work is 88 amperes, so that the efficiency of conversion is 88 per cent; that is, we take into the motor electric energy equal to 100 and deliver power, or mechanical energy, at the pulley equal to 88 per cent.

This test, however, gives no idea of the amount of power the motor develops, because the number of amperes alone is no measure of electrical energy. To find the amount of electrical energy, we must know the potential or voltage of the current. If we have a voltmeter, we can connect it with the motor as explained in Chapter XXIV, Part I, and then by multiplying the volts indicated upon the instrument when connected with the motor terminals, by the current in amperes, we shall get the number of watts of electrical energy given to the motor.

Suppose that the voltage is 100, then the watts when the motor is running loaded and the current is 100 amperes will be $100 \times 100 = 10{,}000$. This is the total amount of electrical energy absorbed, but the portion of this energy that is transformed into useful mechanical energy and delivered at the pulley is 8,800 watts, which is the product of 88 amperes by 100 volts. The energy lost in the motor is 1,200 watts. To find the amount of power delivered at the pulley, in horsepower, we divide the 8,800 watts by 746, this number of watts being equal to 1 horsepower. If the division is made, it will give nearly 12 horsepower.

If we are not provided with a voltmeter, we can come fairly near the real amount of energy by going by the voltage of the line; that is, the voltage it is supposed to have. Thus, if the motor is connected with the circuit from a lighting station that is operated at 220 volts, we can take this figure as approximately correct, and get an indication of the amount of power which will not be more than 6 per cent out of the way, because the actual voltage is not likely to be more than 230 nor less than 210.

In order to make an accurate test, we first ascertain the resistance of the field coils of the motor and also that of the armature. The resistance of these parts will not be the same when

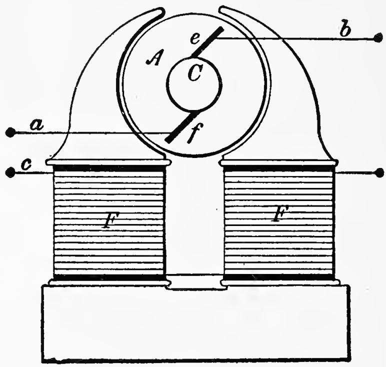

FIG. 217.

the wire is cold as when it is hot; the higher the temperature, the higher the resistance; hence, it is best to run the motor 2 or 3 hours before measuring the resistance, so as to get the armature and the field coils heated up to the temperature that they attain in actual running.

To test the resistance of the coils, the terminals are disconnected from each other, as illustrated in Fig. 217. The best way to test the resistance is by means of a galvanometer and bridge, as explained in Chapter XXVII. The combination of a galvanometer and a bridge is commonly called a testing set, and by many it is known by no other name.

If a testing set is not at hand, the resistance of the arma-

ture and field can be ascertained by means of a voltmeter and an ammeter. This method will enable us to find the resistance of the field with a fair degree of accuracy, but for measuring the resistance of the armature it is practically useless, unless the voltmeter is calibrated to measure very small voltages, say from 5 volts down to a small fraction of 1 volt.

To measure the resistance of either the armature or the field coils by means of a voltmeter and an ammeter, the terminals are connected with the instruments and with a battery or other source of current, as shown in Figs. 218 and 219. In both

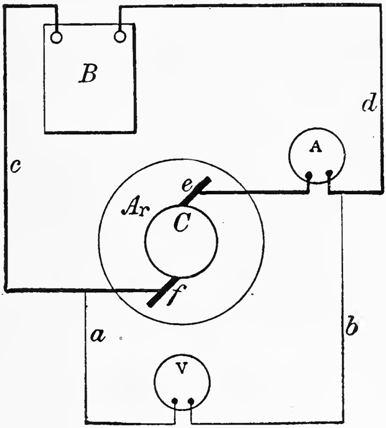

FIG. 218.

of these diagrams *B* represents a battery, which, for testing the armature, should be a storage battery capable of giving a strong current, fully as much as is required to run the motor up to full power. The voltage should not be more than 3 per cent of that required to operate the motor. For testing the field coils, the battery need not give a current of more than an ampere, and in most cases considerably less, but the voltage should be about one-half that for which the motor is designed. Such a voltage cannot be obtained with batteries of any kind without connecting a large number of them in series, say from thirty to seventy.

From the foregoing, it will be seen that it is not convenient to use batteries either for armature or field coil tests, and the best way is to use the same current that runs the motor, introducing a sufficient amount of resistance to cut it down to the required strength.

In Figs. 218 and 219 the connections are shown for testing the armature, but the connections for testing the field are precisely the same.

For the field the resistance can be found with a fair de-

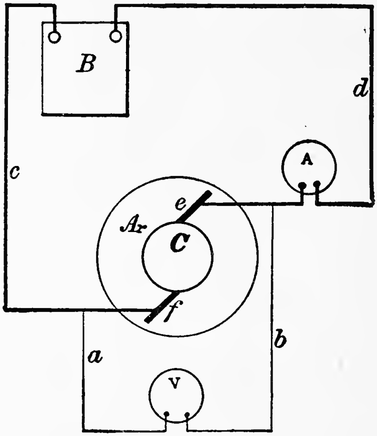

FIG. 219.

gree of accuracy by this method, because, as this resistance is high, the voltage with a small current will be high. To illustrate, suppose that we connect the field as shown in these diagrams, and find that the current is 2 amperes, and the volts 240; then, by dividing the volts by the amperes, we shall get the resistance in ohms, and 240 divided by 2 gives us 120, which is the number of ohms resistance in the field coil.

As the resistance of the armature is very low—generally a few hundredths of an ohm—even with a strong current the voltage is low. Thus, if the resistance of the armature is, say, 0.02 ohm, and we pass through it a current of 100 amperes, the

volts will be only 2. If the voltmeter which we have is one that indicates 100 or more, we shall be unable to determine anything positive about the armature resistance with it, for it is not practicable to measure fractions of a volt with such an instrument. If, however, we have a voltmeter that will measure hundredths of a volt, and indicate as high as 5 volts, we can use it and determine the armature resistance fairly well, following the same rule as for the field coils—that is, divide the volts by the amperes of current, and the quotient will be the resistance in ohms.

By these methods the resistance of the field coils can be measured to within less than 1 per cent, but that of the armature cannot very well be ascertained much closer than 2 or 3 per cent. By the use of the galvanometer and bridge, the resistance can be determined to within a very small fraction of 1 per cent, say the one hundredth part of 1 per cent, so that it is by far the best method of testing, and generally there is no difficulty in obtaining a testing set.

In measuring the armature resistance by means of a voltmeter and an ammeter, measurements should be made with the instruments connected as shown in both the diagrams, and then the average of these should be taken. As can be seen at once, if the voltmeter is connected as in Fig. 218, it will indicate the voltage absorbed by the ammeter as well as by the armature, and although the resistance of the ammeter is very low, its presence in the circuit will increase the voltage reading, on account of the strong current used. If the connections are made as in Fig. 218, the ammeter will indicate the current passing through the voltmeter as well as that passing through the armature, and if the instrument is intended for very low voltages, the current passing through it may be sufficient to slightly increase the reading of the ammeter. Generally, however, this will not be the case, so that in most cases a single reading with the instruments connected as in Fig. 218 will be sufficient.

Having found the resistance of the field coils and that of the armature, we can determine the loss in these two parts separately, and the accuracy with which we determine these two losses will depend upon the accuracy with which we have

measured the resistance. Suppose that the resistance of the field coils is 100 ohms, and that current is supplied to motor at a voltage of 200, then by dividing this voltage by the field resistance we find that the current passing through the field coils is 2 amperes, and multiplying this current by the voltage, we get 400 watts as the energy absorbed in the field coils; and this loss will remain the same no matter whether the motor is running light, or fully loaded.

Armature current will increase with the load, so that the loss due to the resistance of the armature coils will be small when the machine is running free, and will increase as the load increases. Suppose that the armature resistance is 0.02 ohm, and that, when the motor is running fully loaded, the armature current is 100 amperes, then the voltage absorbed by the armature at full load will be 2 volts, being the product of the resistance by the current strength. Multiplying this voltage by the current, we get 200 watts as the loss due to armature resistance when running with full load.

If we now make a test in the manner first explained—that is, by running the motor light and then fully loaded, and take the difference in the current strengths for the two cases—we shall find that it will be more than what is represented by the field coil and armature resistance losses combined. This difference represents the loss that is due to mechanical friction, and also magnetic friction. The mechanical friction is the bearing and armature brush friction and also the resistance of the air rubbing against the rotating parts. The magnetic friction is that within the iron caused by the action of the particles upon each other as the metal is magnetized and demagnetized. This friction is called "hysteresis."

It is difficult to separate the mechanical friction loss from the magnetic friction loss, or hysteresis loss, but generally they are about equal and are practically the same whether the motor is running light or loaded. Assuming this to be the case, we then have three losses that are constant, namely, the field coil loss, the mechanical friction loss, and the hysteresis loss. Now, if we run the motor light and measure the current, we know that of this current a certain amount passes through the field coils, and the balance goes through the armature, one-half be-

ing absorbed by mechanical friction and the other half by hysteresis. The loss in the armature due to the passage of the current through it will increase in proportion to the square of the current.

With these facts determined by our tests, we can draw a diagram such as is shown in Fig. 220, in which the figures on the right-hand side indicate percentage of work utilized or lost, and those along the bottom indicate percentage of rated load.

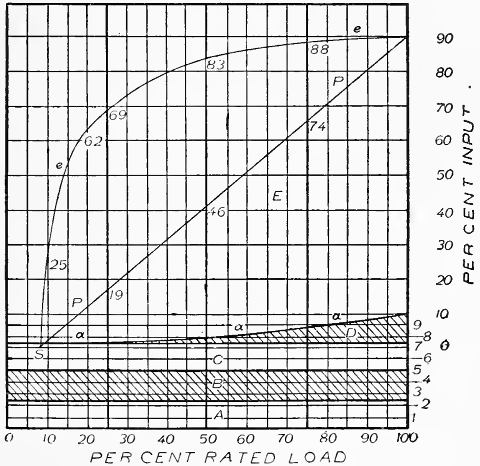

FIG. 220.

In this diagram the lower area, marked *A,* represents the energy lost in the field coils, which, as we have shown, is the same for all loads. The shaded area above this, marked *B,* represents the hysteresis loss, which is also practically constant; in fact, it is absolutely constant at the same speed. The unshaded area, *C,* represents the mechanical friction loss, which is also practically constant. The shaded section above this, marked *D,* which begins at nothing on the left-hand side and becomes wider as it approaches the right-hand side, is the loss due to armature resistance, which is insignificant when the load is light, and in-

creases with increasing load. Thus we find that, if the motor is running without load, the total loss is about 7½ per cent, and when the full load is on it increases to 10 per cent.

If the current absorbed by the motor running at full load is 100 amperes, according to this diagram it will require 7.50 amperes to run light, and at this point, as it does no work, all the energy it receives is lost; hence, the efficiency is zero, and the work done is zero. The curve *e e* represents the efficiency for all loads and, as will be seen, it is 25 per cent for 10 amperes, 62 per cent for 20 amperes and continues to increase, being 88 per cent for 75 amperes, and 90 per cent for 100 amperes. The line *P P* shows what portion of the total capacity of the motor is given with different strengths of current, this being zero for 7.5 amperes, 19 per cent for 25 amperes, and 46 per cent for 50 amperes. These are percentages of the full load capacity, which is 90 per cent of the electrical energy absorbed. To obtain the curves *e e* and *P P*, or the percentage figures marked upon them, all that is necessary is to add to the 7.5 per cent loss with no load the armature loss obtained by multiplying the square of the current by the armature resistance. The upper part of this diagram is drawn to a smaller scale, vertically, than the lower, so as not to make it too high. The No. 7 line is the zero line for the upper part of the diagram and, as will be noticed, curves *e e* and *P P* start from points on this line; to be strictly accurate, they should start from curve *a a*.

CHAPTER XLV.

Testing Electric Motors—*(Continued.)*

IN THE last chapter we explained several methods of testing electric motors by means of electrical instruments. Such tests can also be made by using combinations of electrical instruments and mechanical devices. A common way of making tests by a combination of electrical and mechanical means is illustrated in Fig. 221. In this diagram, *F* represents the motor to be tested, *B* a fan blower that is driven by the motor, and *D* a dynamometer that is interposed between the fan and the motor to measure the power transmitted.

Strictly speaking, the dynamometer *D* does not measure the power transmitted; it simply indicates the force or pull on the belt, and to obtain the power it is necessary to multiply this by the velocity of the belt. Some dynamometers are calibrated to indicate the pull upon the belt, so that to obtain the power in foot-pounds the velocity at which the belt travels in feet per minute must be multiplied by the reading of the instrument. Then, if this product is divided by 33,000, the horse-power is obtained. In other dynamometers, the calibration is such that the number of revolutions per minute is given instead of the belt speed. It is necessary, therefore, before making a test, to ascertain how the dynamometer is calibrated; the name plate on the apparatus usually gives the required information.

Starting from the top of the diagram (Fig. 221), the wires *P N* are connected with the supply circuit, and the ammeter *A* and voltmeter *V* enable us to measure the strength and voltage of the current, the product of these two readings giving the power, as has been explained in previous chapters. By adjusting the outlet gate of the fan *B*, the power required to drive it can be increased or decreased as desired, so that from the dynamometer *D* we can take measurements of the power delivered, and from the instruments *A* and *V* can determine the electrical energy absorbed for full load or for any portion of full load that we may desire. In this way we can determine the relation between en-

ergy received and energy delivered, or the efficiency of conversion, for several proportions of load.

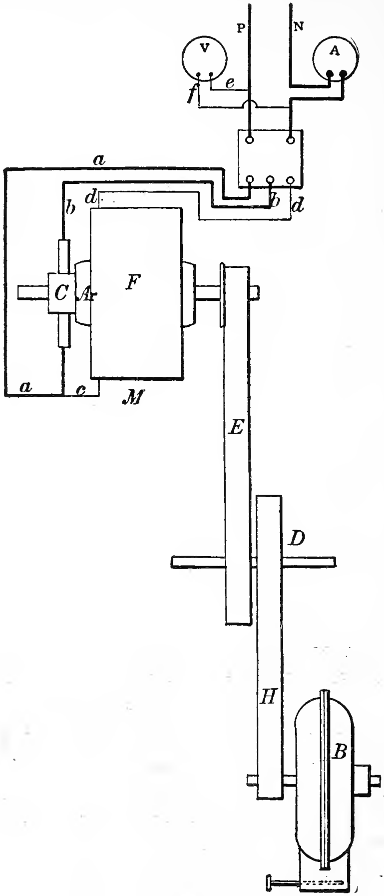

FIG. 221.

In order that a test made in this way may be at all accurate, it is necessary that the indications of the instruments A and V,

and of the dynamometer *D*, as well as the velocity of *D*, or of the belt, as the case may be, be taken at the same instant, or as nearly so as possible; otherwise the results may be far from correct. This liability of error from not taking the readings of the instruments at the same instant arises from the fact that the voltage of the current cannot be depended upon to remain absolutely constant, and any variation in it will cause a material difference in the amount of energy supplied to the motor.

As there is a possibility of making an error in reading the indications of the ammeter and the voltmeter, and as both may not be read at the same time, it is advisable to use a wattmeter as a substitute for these two instruments if one can be obtained. This substitution of one instrument for two reduces materially the liability of making mistakes. A still better plan is to use an integrating wattmeter which will give a true record of the energy that passes through it during a given period. If such an instrument is used, and the test is made to cover a run of 1 hour, the record of the instrument will show the average power during the run. If, during this time, the indication of the dynamometer is taken every minute, we shall have 60 readings from which the average can be obtained by the simple process of adding them all together and dividing the sum by 60. To make the test as accurate as possible, the gate in the end of the blower should be undisturbed during the run, so as to maintain the power practically constant.

By a test made in the manner just explained we get the power delivered by the motor, and the energy absorbed, under actual running conditions, and from these two amounts we can obtain the running efficiency of the motor, as well as its actual capacity in horsepower. But we cannot separate the various losses in the motor, as may be done by means of the purely electrical tests explained in the last chapter. The blower *B*, as will be readily understood, may be replaced by any other kind of machine, or by a number of machines. Thus if the motor is in actual service, the dynamometer *D* can be connected between the motor and the main shaft, the belt from the motor running to the dynamometer, and the belt from the latter to the line shaft. If a test is made of a motor in actual service, it is desirable that during the test the load be kept as nearly uniform as possible.

In many cases, where it is not convenient to use a blower or any other kind of machinery to absorb the power of the motor, if we have a second motor, it may be used as a generator, and be driven by the motor to be tested. Then, by measuring the electric energy absorbed by the motor, and that developed by the generator, we can ascertain the capacity and also the efficiency of the machine. For this kind of test the two motors are arranged as shown in Fig. 222, motor M acting as a motor receiving cur-

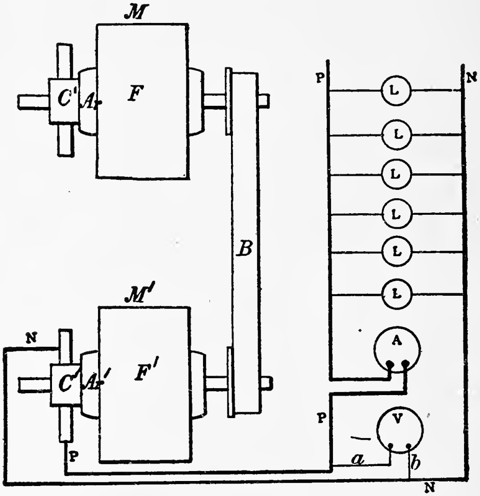

FIG. 222.

rent from the supply mains, while motor M' acts as a generator driven by M through the belt B. The current generated by M' can be utilized in a number of lamps as indicated, or it can be passed through another motor or through a resistance. The current supplied to M from the main circuit is measured in the same way as in Fig 221; that is, by the use of a wattmeter or an ammeter and a voltmeter. The current delivered by M' is measured in the same manner, the instruments A and V representing an ammeter and a voltmeter which may be replaced by a wattmeter if such an instrument is available.

If the two motors M and M' are of the same size and make, we may assume that they are of equal efficiency, and by taking one-half the difference between the energy absorbed by M and that delivered by M', we shall come very near the loss in each machine. This method will not give us a perfectly correct result because the current drawn from the supply circuit by M will be stronger than the current delivered by M', and the loss in M will, therefore, be greater than that in M'; also the loss from slippage of belt is charged against the machines.

If we desire to make the division of the loss more accurately, we can do so by ascribing to each machine a portion of the loss proportional to the energy absorbed or delivered by it. For example, suppose that M absorbs 10 kilowatts and that M' delivers 8 kilowatts; then if the difference between them, which is 2 kilowatts, is divided into 18 parts, and 10 of these are given to M and 8 to M', we shall arrive at nearly the true result. Carrying this calculation further, we shall find that if M loses 10 parts, the total electric energy it develops is 10,000 watts less 10 times $\frac{2,000}{18}$, or 1,110 watts, = 8,890 watts; from which we find that the efficiency of M is about 89 per cent.

If the two machines M and M' are not of the same make, or if they are of different sizes, we can approximate the efficiencies of both by making one test with M running as the motor and another test with M' as the motor and M as the generator. If there is a difference in the efficiency of the two machines, these two tests will not give the same results, so that by comparing them and striking an average, we can come very close to the actual efficiency of each machine.

Another way of testing when we have two motors is to use the current generated by the second machine in driving the first one. For such tests, the motors are connected with each other as shown in Figs. 223 and 224, in both of which M and M' represent the motors and B the connecting belt. This arrangement of motors for testing is extensively used in shops where they are manufactured, its advantages being that, with a comparatively small amount of power, large motors can be tested.

In Figs. 223 and 224 the rectangle B represents a storage

battery, or any other source of current, used to provide the extra power required to drive the motor. If M' is driven at the same speed as M, both machines being alike, the voltage developed by M' will be lower than that required to maintain M at the proper speed. If such is the case, a battery connected in series with the two machines, as in Fig. 223, will supply the additional voltage.

With this arrangement, if we connect voltmeters and an ammeter as indicated in Fig. 223, we shall find that the voltmeter

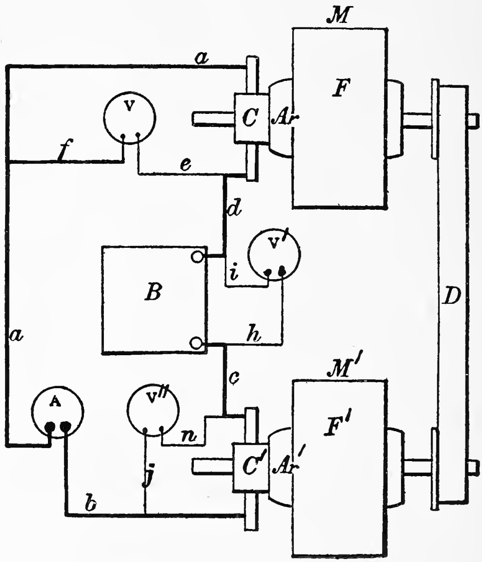

FIG. 223.

V will show a higher electromotive force than V'', and that the difference between them will be the same as the indication of V', thus showing that the battery B adds its voltage to that of M' so as to provide the requisite voltage to drive M at the proper speed. The voltage indicated by instrument V' shows the loss in both machines, because the voltage delivered by M' is not the full voltage which it generates, but it is this voltage less the amount lost within the machine. In the same way, the voltage required

to run M up to full speed is the amount required to impart to the armature this velocity plus enough to cover the loss within the machine.

In Fig. 224 the battery B is connected in parallel with the generator M', and in this case the voltage of both machines is made the same. This result is obtained by proportioning the sizes of the pulleys on M and M' so that the latter may run faster, the difference in speed being dependent upon the difference in

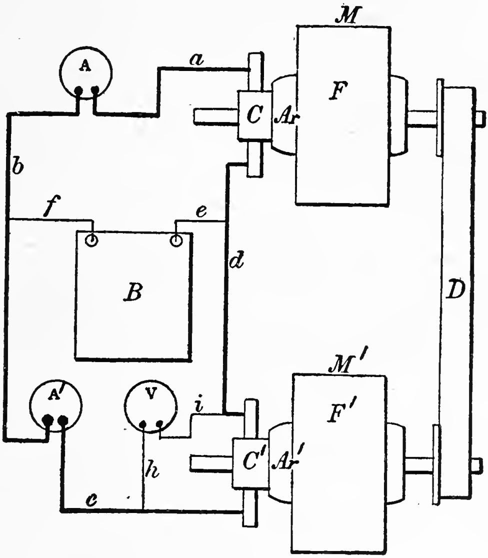

FIG. 224.

voltages at the same velocity. In this case, although M' will provide the proper voltage, it will not furnish all the current required, and to make up the deficiency the battery B is drawn upon. If the ammeters A and A' are examined, it will be found that the former indicates a considerably stronger current than the latter, the difference between the two being supplied by the battery.

If the efficiency of the motors is 90 per cent, the loss of

energy in the two machines will be about 19 per cent, and from this it will be seen that the battery *B* will have to supply only about one-fifth of the current that would be required to drive *M* if it were supplied entirely from an external source. Thus with this arrangement, if we have a generator capable of developing 10 horsepower, we may use it as a substitute for the battery *B* and be able to test motors of 50 horsepower capacity. Hence the general use of this method in motor manufacturing shops.

CHAPTER XLVI.

TESTING ELECTRIC GENERATORS.

TESTING an electric generator is fully as simple as testing an electric motor. In fact, the only real difference is that, in the case of the motor, we measure the amount of electrical energy supplied to the machine and the amount of mechanical energy it gives back, while in the generator test we measure the mechanical energy required to drive the machine and the electrical energy it gives back. In the first case, the difference between the electrical energy absorbed and the mechanical energy given back shows the energy lost in the motor. In the second case the difference between the mechanical energy required to drive the machine and the electrical energy it gives back shows the portion lost in the generator.

In the last chapter we outlined, in connection with the explanation of Fig. 222, the general method pursued in measuring the power developed by a generator; but to make the subject quite clear we present here in Fig. 225 a diagram showing the general arrangement for a complete test. In this diagram, *S* represents a line shaft from which the generator *G* is driven through the belts *B* and *E*. This shaft *S* may be the shaft of a steam engine, or a line shaft driven from any source of power. The belt *B* runs over a pulley of a dynamometer *D*, from which the belt *E* transmits the motion to the generator, the arrangement being precisely similar to that shown in Fig. 221.

Dynamometer *D* enables us to measure the power required to drive the generator, and by means of the voltmeter *V* and the ammeter *A*, we find the electrical energy delivered to the circuit by the generator. The difference between the two amounts is the energy that is lost in the generator, and this, as in the case of a motor, is absorbed partly in the armature and partly in the field. The field loss consists of the energy absorbed in forcing the field current through the field coils, and is measured in precisely the same way as the field loss in a motor—that is, by

multiplying the strength of the field current by the voltage measured across the field terminals.

Another way of finding the field loss is to measure the re-

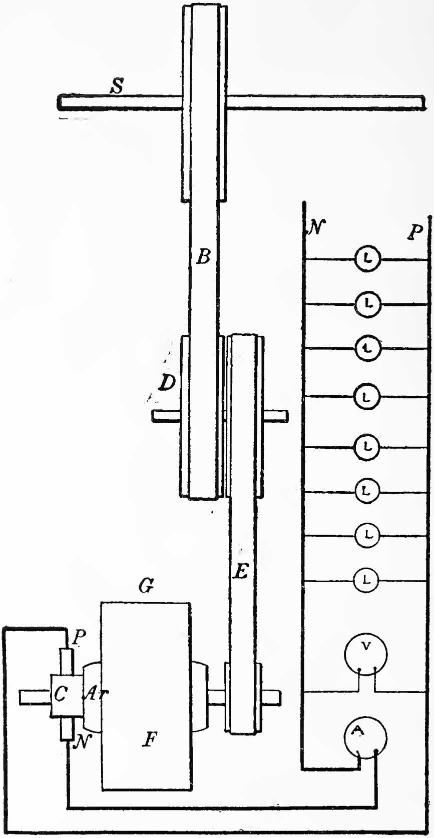

FIG. 225.

sistance of the field coils after they have become heated by a run of 2 or 3 hours, and then multiplying this resistance by the square of the field current, the product being the

energy absorbed by the coils in watts. If we are not provided with an ammeter that will indicate a small current closely, we can calculate it by dividing the voltage of the generator by the resistance of the field coils, and then by multiplying the voltage by this calculated current we can get the watts lost in the field.

In the armature of a generator the losses are the same as in the armature of a motor, and consist of the energy lost in the armature coils (which loss is determined in the same way as the field coil loss), the energy lost by mechanical friction, and that due to hysteresis, which is magnetic friction. These three armature losses are substantially the same in magnitude as they are in the armature of a motor, so that, if we draw a diagram like Fig. 220, the portions that represent the three armature losses and the one field loss will be the same as in the motor diagram.

Resistances of the armature and field of the generator are obtained in the same way as in the motor, as explained in connection with Fig. 217.

In testing generators, as well as motors, considerable work can be saved if we have wattmeters, as well as ammeters and voltmeters. Thus by connecting a wattmeter in the field coil circuit we can obtain the watts lost in the field by simply reading the dial of the instrument. If we connect a wattmeter in the main circuit, we can read on its dial the watts delivered to the external circuit, and thus save the trouble of multiplying the indication of the voltmeter V of Fig. 225 by the indication of the ammeter A. If the wattmeter is an accurate instrument, we shall be able to obtain more accurate results with it than with the ammeter and voltmeter, for the simple reason that in reading one instrument there is but one chance for making a mistake, while in reading two instruments there are two chances, and any mistake made in reading either instrument is magnified by being multiplied by the reading of the other instrument.

In the last two chapters we explained only the course to pursue in testing shunt-wound motors, and what we have said up to this point in this chapter relates only to shunt-wound generators. At the present time nearly all stationary motors are of the shunt type, but generators are as a rule compound wound. The difference between these two types, as has been explained in previous

chapters, is that the field of the compound machine is magnetized by two sets of coils, one being the regular shunt coils, the other being a set of series coils through which all the current that flows through the armature is passed.

In testing compound-wound motors, as well as compound-wound generators, all that is necessary in addition to what has been explained in connection with shunt machines, is to determine the loss of energy in the series coils, and this is easily done by measuring the resistance of these coils, when heated by a run of several hours, and then multiplying this resistance by the square of the current that passes through the coils.

If a compound-wound generator is well proportioned, it will be found that the loss of energy in the shunt coils of the field will be less than in a simple, shunt-wound generator, and that when the loss in the series coils is added to that in the shunt, the sum total will be about the same as in the simple shunt machine, or possibly a trifle less.

Motors have series coils, in some cases, and are designated as compound-wound or as differential-wound motors, depending upon the way in which the series coils are connected. If the motor is compound-wound, the series coils are connected so that the current flowing through them runs in the same direction as that in the shunt coils, and in that case the series coils help the shunt coils to magnetize the machine. If the motor is differential-wound, the series coils are so connected that the current flows through them in the opposite direction to the current flowing through the shunt coils, and in that case the series coils act in opposition to the shunt coils; that is, they demagnetize the machine, so that the net strength of the field magnets is due to the difference between the magnetizing effects of the series and the shunt coils. It is on this account that this method of connection is called a differential winding. In a compound-wound motor the effect of the series coils is to cause the speed to drop faster than with the simple shunt coils, when the load is increased. The effect of the differential winding is to cause the speed to drop less when the load is increased. The compound winding is used on motors for the purpose of giving a strong turning effort or torque with a comparatively small current. This winding is commonly used for elevator motors and for other purposes where the ma-

chine has to start up under full load. In such cases, a simple shunt motor will take an excessively strong current to start, because the field is comparatively weak; but if a compound winding is used, the field will be very strong because the full armature current will pass through the series field coils and thus greatly reinforce the action of the shunt coils. A shunt motor can be made so as to start up under full load with a current no greater than compound motors generally require, but if so made means must be provided to cut down the field current after starting in order to enable the motor to run up to full speed.

In a differential-wound motor, the starting current under a full load is much greater than in a simple shunt machine, because the series coils act to demagnetize the field, and on that account the torque, or rotative force of the armature, for a given strength of current is considerably reduced. The differential winding, however, will cause the motor to run at a more uniform speed, because when the load increases the field becomes weaker, and on that account the armature has to make more turns in a given time to develop the counterelectromotive force required to balance the line voltage.

This advantage of the differential winding in the way of producing more constant speed is not as great as might appear, since the series coils, while acting to reduce the voltage developed by the armature for each revolution, also act to reduce the total counter voltage required, on account of their absorbing a considerable portion of the line voltage. Because of the fact that designers are able nowadays to obtain about as close regulation of speed with the simple shunt winding as can be obtained with the differential, the latter type is seldom used in modern machines.

Between motors and generators there are some relations that can be easily explained by the aid of four simple diagrams, Figs. 226 to 229.

One of the most important things to fully understand is that there is no difference whatever in the principle of action or construction between a motor and a generator. In the actual machines there are, generally, some slight differences in the details of design, but these are made simply that each type of machine may be better adapted for the class of work it has to perform.

If allowed to run free, a simple shunt-wound motor will attain a speed sufficient to cut the armature current down to a value so low that the energy passing through the armature is just enough to overcome the electrical and magnetic losses and the mechanical resistance to rotation. If, at this point, we put a belt on the pulley and apply power by means of it so as to increase the speed of the motor, the result will be that the current passing through the armature will be still further reduced, and if we continue to increase the speed, the current will keep on reducing until it becomes zero.

Current reduces as the speed is increased because the armature of the motor develops a voltage in the opposite direction to that of the line current, and this acts as a back pressure to hold

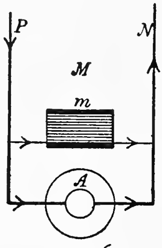

FIG 226.

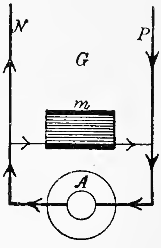

FIG. 227.

the line current back. This voltage, which is called the counter-electromotive force of the motor armature, or sometimes the back pressure, puts forth an effort to set a current flowing through the armature circuit in the opposite direction. The back pressure increases as the armature speed increases, and at a velocity slightly above that at which the motor will run free the back pressure becomes equal to the line voltage, so that the current flowing through the armature is reduced to nothing, because the two forces just balance each other.

If now the armature speed is further increased, the back pressure will become greater than the forward, or line, pressure, and as a result the armature of the motor will generate a current that will flow back into the main line. Thus it will be seen that if we increase the velocity of the motor sufficiently, we convert it into a generator.

From the foregoing it will be seen that a shunt-wound motor without any changes in the wire connections, or in the direction of rotation, becomes a generator, if we only increase the velocity at which the armature rotates. By looking at Figs. 226 and 227 it can be seen why no changes in the connections or direction of rotation are required.

In Fig. 226 it must be remembered that the machine is acting as a motor, and that the line current comes in through the positive wire P, hence it will branch through the shunt field coil m and through the armature A in the direction indicated by the

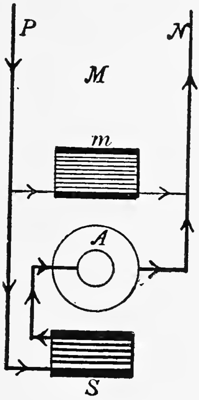

FIG. 228.

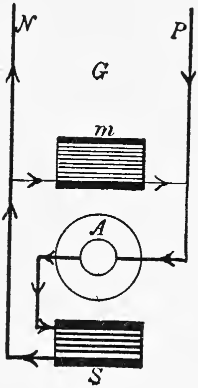

FIG. 229.

arrow heads. In Fig. 227, when the machine is acting as a generator, the current comes from the armature A and it flows through this in the opposite direction, being driven by the back pressure. Now this current, when it reaches the shunt field coil m, will flow through it in the same direction as the line current did, when the machine was running as a motor, as is clearly shown by the arrow heads; but passing out into the main current wires P and N, it will flow against the line voltage; that is, the motor now feeds current into the main line instead of drawing from it. If the direction of rotation of the armature is reversed, when the motor is acting as a generator, no current will

be generated unless the connections of the field coil are also reversed.

If a differential-wound motor is driven above speed by the application of power, it will become a compound-wound generator, as can be seen by comparing Figs. 228 and 229, the first showing the series coil *S* connected so that the current flows through it in the opposite direction to that through the shunt coil *m;* that is, in the direction of a differential winding. In Fig. 229, which shows the direction of field currents through both field coils, when the machine is running as a generator, it will be seen that in both coils the direction of current is the same; hence, a differential-wound motor, when driven above speed, becomes a compound-wound generator, and conversely a compound-wound motor, when driven above speed, becomes a differential-wound generator. As in the case of the shunt-wound motor, no change is made either in the direction of rotation or the wire connections to convert the motor into a generator, a slight increase in speed being all that is required.

CHAPTER XLVII.

STORAGE BATTERIES.

STORAGE batteries are simply devices which transform electrical energy into chemical energy and vice-versa. They do not store electrical energy, because such a thing is impossible. Electricity is simply a force of nature; it is not a material thing that can be bottled up. To charge a storage battery an electric current is passed through it; this current produces a chemical action which leaves the contents of the battery in what may be called an unnatural chemical state, and, as a consequence, they will restore themselves to the natural state as soon as the conditions are such that they can, and in this restoration an electric current will be generated.

The amount of electrical energy put into a storage battery is more than that which can be recovered from it, because a portion of the energy is absorbed in overcoming the resistance that opposes the passage of the current. This resistance hinders the flow of current when the battery is being charged, and also when it is being discharged, so that there is a loss in both operations. If the battery is allowed to stand but a short time after being charged, and is charged and discharged at a moderate rate, the loss will not be more than 10 per cent; but if the charging and discharging are both forced—that is, if the battery is charged and discharged in a short time—the loss may be much greater, possibly as much as 50 per cent.

When a storage battery is fully discharged (in a practical sense), its energy is not entirely exhausted; it is simply run down to a point beyond which it is not advisable to carry it in practice. A storage battery might be compared to a water pail having a sponge fastened to its bottom. If the pail is filled with water and then emptied, it will not give out all that was put into it, because the sponge will soak up some of the water. If it required 10 quarts to fill it, and the sponge retained 2 quarts, then on pouring out the water only 8 quarts would be obtained. A greater amount of water could be forced out of it by squeezing the sponge. If the pail is filled the second time, it will require

only 8 quarts because the sponge, being full, will not soak up any more; so that when emptied the second time, as much water will be poured out as was poured in.

From this it will be seen that after the first filling, all that will be lost will be the power required to fill the pail with water and to empty it. This is precisely the case with the storage battery after it is once charged; all that is lost in the successive charging and discharging is the power absorbed by the electrical resistance.

Storage battery cells have an e. m. f. of about 2 volts each. When fully charged, the voltage is about 2.1, and when discharged it is about 1.8. In practice it is found that storage battery cells do not work well when connected in parallel, owing to the fact that when so connected some of the cells will give a stronger current than the others, and thus run down sooner. On that account, the cells are made of such size that one will have all the current capacity required. Thus, if the maximum demand of the circuit is 10 amperes, the cells will be made of such size as to deliver 10 amperes, and if the demand is for 1,000 amperes, each cell will be capable of delivering that number of amperes. The voltage required is obtained by connecting a sufficient number of cells in series; for example, if the voltage required is 100, about fifty cells will be used.

Small storage batteries can be placed on shelves secured to the wall, but with batteries of the sizes ordinarily used in connection with electric lighting plants, they must be placed upon the floor or in strongly constructed racks, as they are too large and heavy to be safely held on shelving. Where floor space is not cramped, the best arrangement is to locate the cells in a single tier, but if there is a scarcity of room they can be placed two or even three tiers high, being supported by strong framing made either of iron or wood. If the framing is of iron, strong insulators must be provided to hold the cells so that they may be well insulated from the ground.

When the cells are placed directly upon the floor, wooden stringers are provided, as is illustrated in Figs. 230 and 231 at *A*. The first figure is a side view of a number of cells and the second is an end view of two rows. The wooden supports should be beams about 4 by 8 inches, set on edge, and should be well im-

pregnated with oil or paraffin to make them water proof. In addition to this treatment, they must be covered with a good coating of coal tar, so that they may not be affected by the acid that is likely to be dropped upon them from time to time. The plates

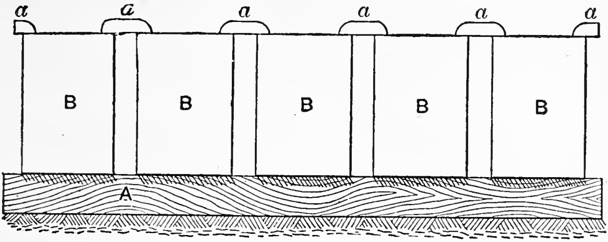

FIG. 230.

in the cells are provided with lugs by means of which they are connected with the plates of adjoining cells; and the distance between the cells must be such that these lugs may be properly connected, as is shown at *a a* in Fig. 230.

If the length of the room is such that all the cells required

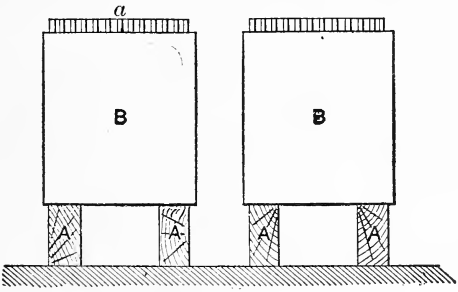

FIG. 231.

can be placed in two rows, they can be arranged with a passageway between them; that is, one row on each side of the room, or they can be placed in the center of the room with a passage on each side. The first arrangement is the more desirable, if the room is narrow. If the room is wide and short, so that the cells

have to be placed in more than two rows, then they should be set in pairs of rows, with a passageway between each pair.

Storage batteries are used to increase the voltage when for any reason it is required to feed a current of higher e. m. f. than the normal into some branch of the circuit. For example, suppose that in a lighting plant where the normal voltage is 110 it is desired to have a current of 150 volts for some particular purpose; then a storage battery capable of furnishing the extra 40 volts is provided and the generator current is passed through the battery so that the voltage of the latter may be added to it. And in this way the 110 volts of the generator, plus the 40 volts of the battery, will give the 150 volts required. If the high-voltage current is not required all the time, the battery is charged by the generator while the high-voltage circuit is shut down. If the high-voltage current is required during all the time the plant is running, or for nearly all the time, two sets of batteries will be used, and one will be charged while the other one is being used.

The most common and profitable use to which storage batteries are put is as a help to the generators. To illustrate their advantage in such cases, suppose that we have a lighting plant used in a factory to furnish light for an hour or less in the morning, and a similar length of time in the evening. Let the maximum number of lights used be one thousand; then it is evident that a generator of one thousand-light capacity must be installed, and power sufficient to drive it must be provided. If the lights are used for 1 hour in the morning and 1 hour in the evening, the generator will be in service for only 2 hours out of the 10 If a storage battery is provided, and this is charged during the remaining 8 hours, it will have to be charged at a rate only slightly more than two hundred and fifty lights; for to feed this number of lights for 8 hours will require just the same amount of energy as to feed four times the number for 2 hours. This being the case, with the help of the storage battery a generator of three hundred-light capacity will be sufficient to do the work, and the steam engine capacity will be reduced in like proportion.

In nearly all the large electric lighting stations, storage batteries are used. Old stations that were not provided originally with batteries install them when the demand for lights becomes so great that they cannot meet it with the generators running up

to full capacity. In all lighting stations the demand for lights is not uniform throughout the 24 hours. It is heavy from 5 to 11 o'clock in the evening and from about 6 to 8 o'clock in the morning. During the day hours it is light, and from midnight to 6 in the morning still lighter.

During the hours of light demand, the storage battery is charged, and when the heavy load comes on, the battery is connected so as to discharge into the circuit and help the generators. In this way the capacity of the station is considerably increased, for to the maximum capacity of the generators is added the capacity of the battery. Another advantage of the battery is that, if for any reason the generators have to be shut down for a half hour or so, the battery can furnish the current, and thus avoid extinguishing the lights.

Diagrams 232 and 233 show the way in which batteries are connected so as to be used to assist the generators in supplying a system of lighting for either a private or public plant. In both these arrangements the battery can be charged while the lamp circuits are being fed, and when it is charged it can be connected to the lamp circuits and work together with the generator or alone, as the case may require.

As stated in the foregoing, the voltage of battery cells varies from about 2.1 down to 1.8 volts, between full charge and discharge. Owing to this change in the voltage, the number of cells connected in series will have to be more when the battery is nearly discharged than when it is fully charged, so as to keep the line voltage up to the proper point. In charging a battery the voltage of the charging current has to be increased as the charging progresses, so as to force a current through the cells against their constantly increasing voltage. On this account the number of cells connected in series has to be reduced as the charging increases, otherwise the generator electromotive force would not be able to set up current to charge the battery.

To obtain the necessary adjustment the battery is divided into two parts, one called the main battery, which is shown at B in the diagrams, and the other, the end regulating cells, shown at B'.

In both the diagrams the generator is represented by A and M, the former being the armature, and the latter the field coils,

and *R* is the field regulator. At *A′* an ammeter is placed to indicate the strength of the generator current, and at *A″* is another ammeter that indicates the strength of the current flowing through the battery. The double throw switch *g* is for the pur-

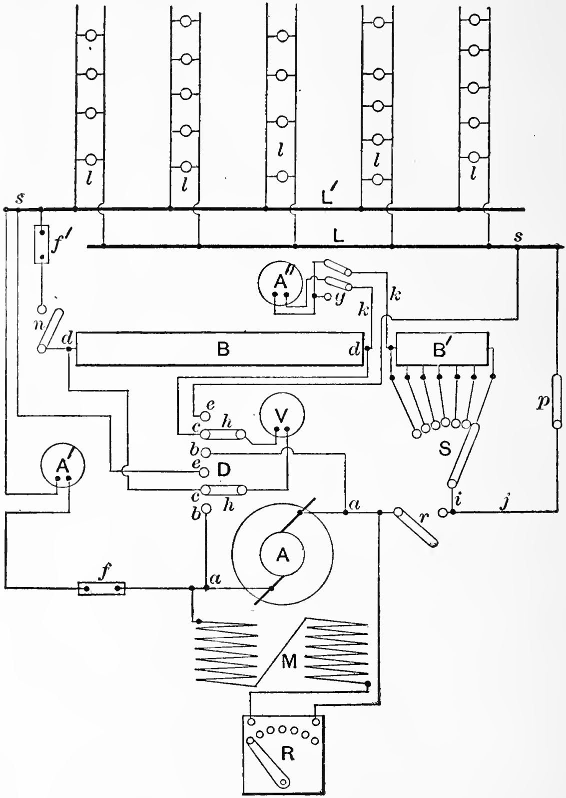

FIG. 232.

pose of reversing the current through *A″* when the battery is being charged, but if an instrument is used which indicates with current flowing in either direction, this switch is not required. In Fig. 232, *V* is a voltmeter which, by means of the switch *D*,

can be connected with the generator, the battery or the bus bars L L', and thus show the voltage of any of these. In Fig. 233, three voltmeters are provided, which is a more con-

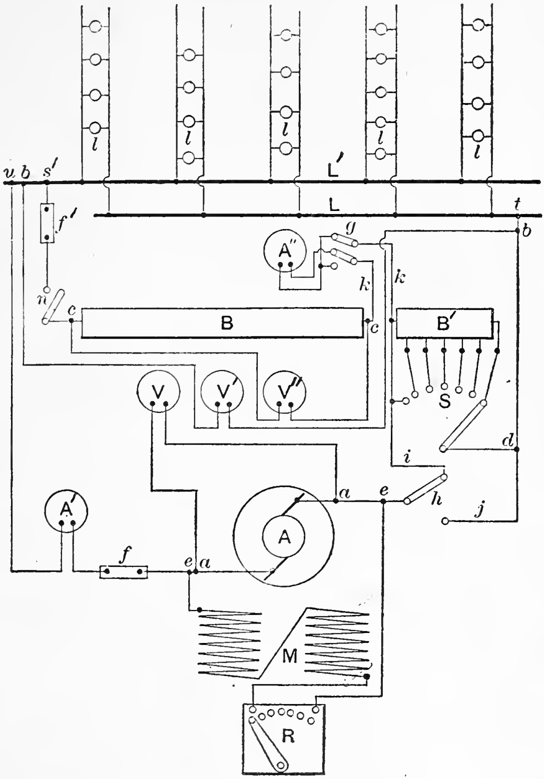

FIG. 233.

venient but more expensive arrangement. The safety fuses or circuit breakers are shown at f and f'.

In Fig. 232, if the switch r is open, as shown, the circuit will be fed from the battery; by moving the switch S, more or less of the regulating cells in B' can be placed in the circuit so as to

obtain the proper voltage. When the switch *r* is closed, the generator will send a current into the circuit, and if switch *S* is now turned far enough to the left the generator current will be forced through the battery and will charge it, provided switch *n* is closed. The current passing through the battery from the generator will reach bus *L′* and from there return to the generator. By moving switch *S* far enough to the right, the number of end regulating cells in *B′* added to the battery can be made sufficient to cause the battery voltage to equal that of the generator, and then the battery current will join that from the generator and flow out to the lamps. Thus it will be seen that by changing the position of switch *S* the battery can be either charged or discharged while the generator is feeding the lamps.

The difference between Figs. 232 and 233 is in the way in which the end-regulating cells are connected in the circuit. In the latter figure, with switch *h* in the position shown and switch *n* closed, the generator current will have to pass through all the end cells *B′* to reach the lamp circuits; while by passing through the main battery *B* it can return to the starting point. From this it will be seen that by moving the switch *S* so as to increase or decrease the number of cells in *B′* the proportion of current passing through the battery and out to the lamps can be varied. When switch *h* is turned so as to connect with *j*, the generator current will pass out directly to the line the same as when switch *r* in Fig. 232 is closed. In either arrangement, the current flowing through the battery can be adjusted by the movement of switch *S*.

INDEX.

A.

B.

C.

D.

I.

L.

M.

S.

T.

V.

W.

For Index to Part I. see end of Part I.